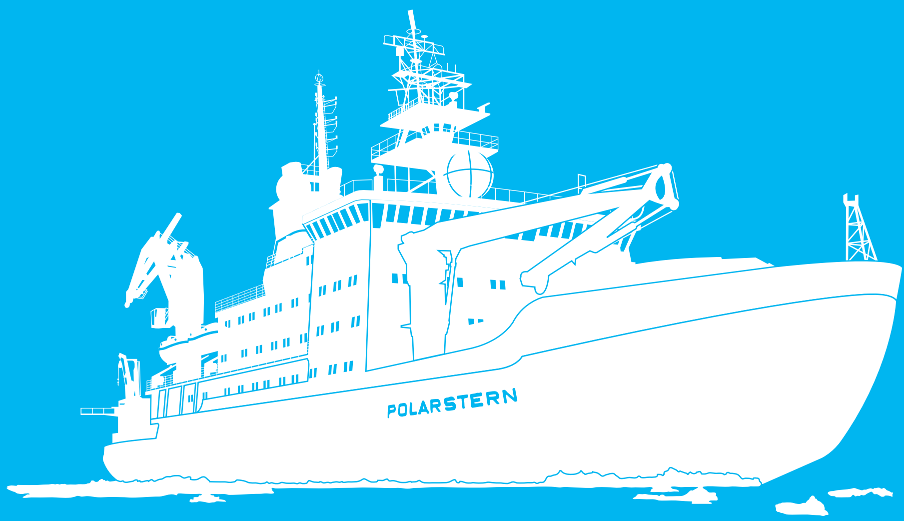
ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR-
UND MEERESFORSCHUNG

EXPEDITION PROGRAMME PS131

Polarstern

PS131
Bremerhaven - Bremerhaven
27 June 2022 - 17 August 2022

Coordinator:	Ingo Schewe
Chief Scientist:	Torsten Kanzow



HELMHOLTZ

Bremerhaven, June 2022

Alfred-Wegener-Institut
Helmholtz-Zentrum
für Polar- und Meeresforschung
Am Handelshafen 12
D-27570 Bremerhaven

Telefon:	+49 471 4831-0
Telefax:	+49 471 4831-1149
E-Mail:	info@awi.de

Website:	http://www.awi.de
Email Coordinator:	ingo.schewe@awi.de
Email Chief Scientists:	torsten.kanzow@awi.de

The Expedition Programme *Polarstern* is issued by
the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) in Bremerhaven, Germany.

Editorial editing and layout
Susan Amir Sawadkuhi

Alfred-Wegener-Institut
Helmholtz-Zentrum für Polar- und Meeresforschung
Am Handelshafen 12
27570 Bremerhaven
Germany

www.awi.de
www.awi.de/en/reports

PS131 – ATWAICE

27 June 2022 – 17 August 2022

Bremerhaven – Bremerhaven

Chief scientist
Torsten Kanzow

Coordinator
Ingo Schewe

Contents

1. ÜBERBLICK UND FAHRTVERLAUF

Torsten Kanzow DE.AWI

Die ATWAICE Expedition nimmt sich zentralen Zielen des POF-IV Programms des Forschungsbereichs “Erde und Umwelt” der Helmholtz-Gemeinschaft mit einem Fokus auf den Themen “Ocean and Cryosphere in Climate” and “Marine and Polar Life” an. In den letzten 40 Jahren ist die sommerliche arktische Meereisausdehnung um 40 % zurückgegangen. Das westliche Nansenbecken und die Framstraße stellen hierbei Gebiete intensivster Wechselwirkung zwischen dem warmen, nährstoffreichen Atlantikwasser (AW) und dem Meereis dar. Hier teilt sich der Westspitzbergenstrom (WSS) in verschiedene, ablandige Zweige auf, die das AW zur Meereiskante befördern. Somit ist die Eisrandzone (ERZ) durch markante Fronten gekennzeichnet, die eine starke Kontrolle auf das Meereis, die Biologie sowie den Wärmeaustausch zwischen Luft und Wasser ausüben.

Unsere Arbeit ist vier Zielen zugeordnet. Hauptsächlich soll eine Prozessstudie bzgl. der ozeanischen Kontrolle der Meereis-Schmelze in der ERZ nördlich von Spitzbergen durchgeführt werden. Schlüsselaspekte sind hierbei Wärmeflüsse im Ozean am Übergang zum Meereis und zur Atmosphäre, Meereis-Deckschicht-Haloklinenkopplung, Frontenprozesse, Meereiseigenschaften und Dynamik in der ERZ. Die Studie wird durch atmosphärische Studien ergänzt, die Eigenschaften und Flüsse von Aerosolen und Treibhausgasen in der atmosphärischen Grenzschicht sowie die Verteilungen von Wasserdampf und Wolken untersuchen. Desweiteren erforschen wir in der ERZ, wie (sub)mesosklalige Strukturen (Fronten, Wirbel, Eisrand) und Meereiseigenschaften (Schmelztümpel, Lichtdurchlässigkeit) die Nährstoffversorgung der euphotischen Zone, die Verteilungen von Phyto- und Zooplankton (einschließlich Quallen), die Primär- und Gemeinschaftsproduktion und den Kohlenstoffexport beeinflussen. Die ERZ Arbeiten finden in dem Gebiet in Abb. 1.1 statt, das mit I-M-O gekennzeichnet ist. Sie basieren auf einem Multi-Plattform Ansatz in dem eisschollen-, schiffs-, verankerungs- und helikopterbasierte Messungen kombiniert werden (Abb. 1.2).

Das zweite Ziel der Expedition stellt die Fortführung des verankerungsbasierten Langzeit-Monitorings der Austauschzirkulation in der Fram Straße als Teil der interdisziplinären Infrastruktur FRAM des AWI dar – einem Beitrag zu dringend benötigen Langzeitbeobachtungsprogrammen an Schlüsselregionen im Ozean, um anthropogene Änderungen quantifizieren zu können. Wir werden das seit 1997 betriebene Array warten, das aus Stationen im WSC (s. Abb. 1.1) sowie der zentralen und westlichen Framstraße besteht, die sich in den letzten Jahren in ein integriertes, interdisziplinäres System zur Beobachtung der Kopplung von physikalischen und biologischen Prozessen entwickelt haben. Die Messungen dienen zur Beantwortung der Frage, wie sich die Eigenschaften des AW Einstroms an einem der Hauptdurchlässe zum Arktischen Ozean verändern und wie diese Änderungen den Arktischen Ozean beeinflussen.

Darüber hinaus (Ziel 3) erforscht die ATWAICE Expedition die ozeanischen Einflüsse auf marine Gletscher in Nordostgrönland. Sowohl der 79Nord Gletscher (79NG; siehe Abb.1.1) als auch der Zachariae Isstroem (ZI) weisen einen ozean-bedingten Eisrückgang und eine Beschleunigung des Eisstroms auf, wodurch sie zum Meereisspiegelanstieg beitragen. Wir planen Verankerungen zu installieren, um die Sensitivität der ozeanisch bedingten Gletscherschmelze gegenüber den sich am ZI und 79NG verändernden Umweltbedingungen zu erkunden. Ergänzend hierzu finden geodätisch-glaziologische Studien statt, die i. Raten und Verteilungen der vertikalen Bewegungen des festen Untergrundes auf Grund von glazialer isostatischer Anpassung mittels GPS-Messungen untersuchen und ii. die zeitlichen Schwankungen supraglazialer Seen mittels *in-situ* Messungen erkunden.

Eine lithosphärische Studie im Aurora Vent-Field (Fig. 1.1.), am westlichen Ende des Gakkelrückens, stellt die vierte Aufgabe der Expedition dar. Um zu erkunden aus welchen Quellen die Vents die Wärme beziehen, die die starke hydrothermale Zirkulation antreibt, werden wir Ozeanboden-Seismometer und ozeanische Verankerungen für die Dauer von einem Jahr auslegen, um die seismologische Aktivität und die physikalischen Eigenschaften des Hydrothermalplumes gleichzeitig zu erfassen.

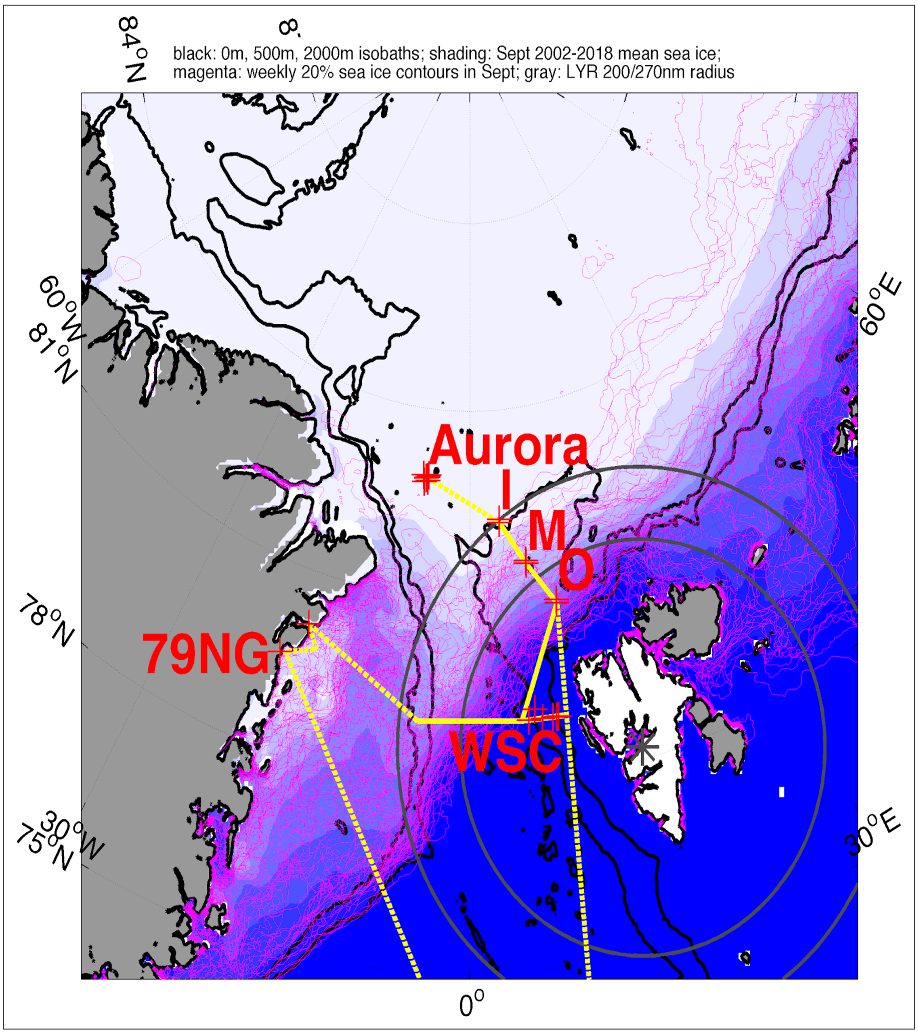


Abb. 1.1: Arbeitsgebiete der ATWAICE Expedition. Folgende Akronyme werden verwendet: 79NG: 79 Nord Gletscher, WSC: Westspitzbergenstrom; Orte in der ERC nördlich von Svalbard (O offenes Wasser, M Eisrand, I Packeis); und Aurora: Aurora Vent Field. Die Verankerungspositionen sind als rote "+" gezeigt. Transitstecken sind als gestrichelte und Schnitte als durchgezogene Linien dargestellt.

Fig. 1.1: Working areas of the ATWAICE expedition. The following acronyms are used: 79NG: 79 North Glacier, WSC: West Spitsbergen Current; sites in the MIZ north of Svalbard (O open water, M marginal ice, I pack ice); and Aurora: Aurora vent field. The mooring locations are shown as red. Transit is indicated as dashed yellow and sections as solid yellow.

Polarstern wird zur Expedition am 26. Juni von Bremerhaven zur ATWAICE Expedition aufbrechen. Nach Ankunft in der Framstraße werden wir zunächst das FRAM Verankerungsarray austauschen. Danach beginnen wir nördlich von Spitzbergen die Prozessstudie zur ozean-getriebenen Eisschmelze in der ERZ. Es folgt ein Abstecher weiter nördlich zum Aurora Vent Field zur Auslegung der Seismometer und Verankerungen. Danach kehren wir wieder in die ERZ zurück und setzen die Prozessstudie fort. Als letztes Arbeitsgebiet laufen wir die Nordostküste Grönlands nahe dem 79NG an, um den Ozean bedingten Gletscherrückzug zu erforschen. Obwohl wir die diplomatische Erlaubnis zur Bergung dreier Verankerungen im Scoresbysund zusätzlich beantragt haben, werden wir diese Arbeiten höchstwahrscheinlich während einer separaten Expedition durchführen. Nach Beendigung des Arbeitsprogramms kehren wir auf direktem Wege nach Bremerhaven zurück, wo die Expedition am 17. August zu Ende gehen wird.

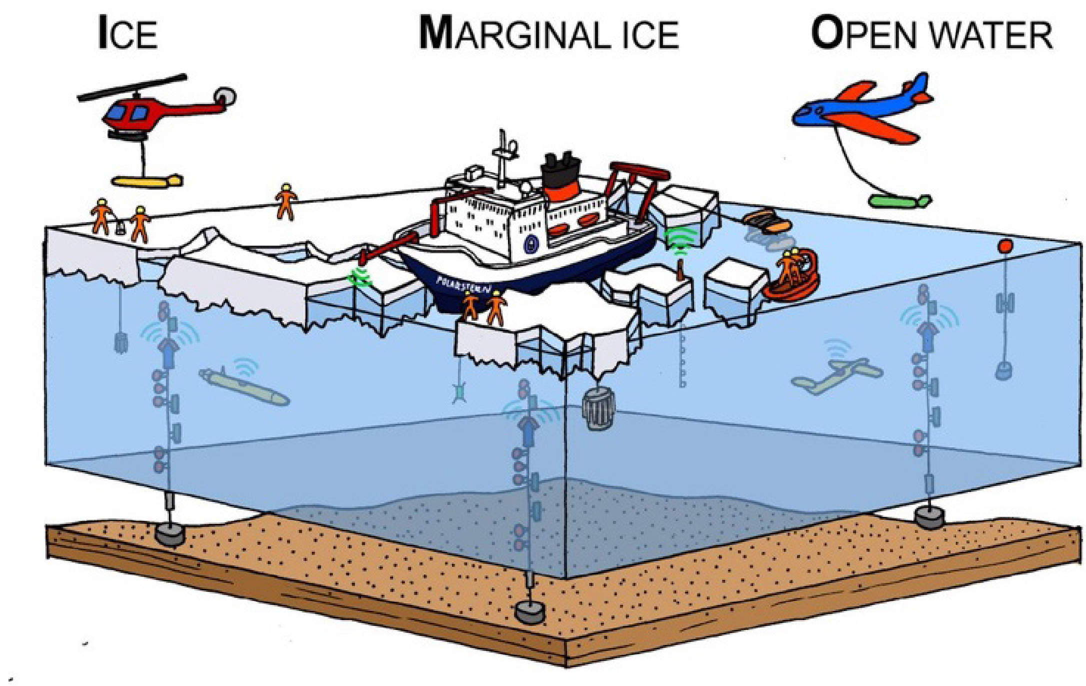


Abb. 1.2: Schema der geplanten Arbeiten in der ERZ (I-M-O Schnitt in Abb. 1.1); Verankerungen werden an allen Orten ausgelegt, und geschleppte (topAWI) und stationsbasierte Messungen werden von Polarstern durchgeführt. Unsere Arbeiten involvieren auch Meereis und Ozean-Messungen von Eisschollen und Meereiskartierungen mittels der Polarstern Hubschrauber. Autonome, eisgebundene Bojen sowie Gleiter kommen zum Einsatz. ATWAICE wird mit einer Flugzeug-Kampagne kombiniert (Oktober 2022; PI: A. Herber, AWI).

Fig. 1.2: Sketch of the work planned in the MIZ (I-M-O line in Fig. 1.1). Moorings will be deployed at all sites, and towed (topAWI) and station-based measurements will be carried out by Polarstern. Our work involves ocean and sea ice measurements on ice floes and sea ice surveys using the Polarstern helicopter. Autonomous, ice-tethered buoys and gliders will be operated. ATWAICE shall be combined with an aircraft-based campaign (Oktober 2022; PI A. Herber, AWI)

SUMMARY AND ITINERARY

Torsten Kanzow DE.AWI

The ATWAICE expedition (PS131) addresses important goals defined in the new programme POF IV of the research field “Earth and Environment” of the Helmholtz Association with a focus on Topic 2: “Ocean and Cryosphere in Climate” and Topic 6: “Marine and Polar Life”. In the past 40 years summer sea ice extent in the Arctic has decreased by 40 %. The western Nansen Basin and Fram Strait represent areas of most intense interaction between the warm, nutrient-enriched Atlantic Water (AW) and sea ice. Here, the West Spitsbergen Current (WSC) is split into different offshore branches, transporting the AW away from the shelfbreak toward the ice edge. As such, the marginal ice zone (MIZ) found in this area features pronounced frontal zones that exert strong controls on the melt and formation of sea ice, the biology, biogeochemistry, and air-sea heat exchange.

Our work can be divided into four major aims. Objective 1 is a multidisciplinary process study of ocean controls on sea ice melt in the MIZ north of Svalbard. We will focus on heat fluxes in the ocean-ice-air system, sea ice-ocean mixed layer-halocline coupling, frontal processes, sea ice properties and sea ice dynamics in the MIZ.

The study will be complemented by investigations of variabilities of i. fluxes and properties both aerosol particles and greenhouse gas in the Arctic marine boundary layer, and ii. atmospheric water vapor and liquid-bearing clouds.

We further study how the (sub-)mesoscale ocean structures (fronts, ice-edge, eddies, etc.) and sea ice properties (e.g. melt ponds, light transmission) affect nutrient supply to the euphotic zone, phytoplankton and zooplankton composition (including gelatinous zooplankton), primary and net community production, and carbon export. This MIZ work will take place in the area marked by the stations I-M-O in Figure 1.1. The work constitutes a multi-platform approach, making ship-based, mooring-based, ice floe-based and helicopter-based measurements (Fig.1.2).

Objective 2 of ATWAICE represents the continuation of the mooring-based long-term monitoring of the exchange flows in Fram Strait (as part of AWI’s interdisciplinary FRAM infrastructure in the Arctic Ocean) – realizing the strong need for long-term year-round monitoring programmes at key ocean sites in order to quantify anthropogenically-introduced changes. We will service the mooring array which started in 1997. It is composed of sites in the WSC as well as central and western Fram Strait, which in recent years have developed into an integrated, interdisciplinary observing system of physical-biological coupling. Our key question is how the properties of the AW inflow change at one of the main Arctic Ocean gateways and how the changes influence the wider Arctic environment.

Objective 3 targets ocean impacts on major marine-terminating glaciers in Northeast Greenland. Both 79 North Glacier (79NG; for location see Fig. 1.1) and Zachariae Isstoem (ZI), show ocean-driven thinning and acceleration thereby contributing to sea level rise. We aim to implement sustained monitoring capacities in order to study the sensitivities of present-day ocean-driven melt to changing environmental conditions at 79NG and ZI. This study is complemented geodetic-glaciological investigations targeting i. rates and spatial distributions of vertical ground movement due to glacial isostatic adjustment (GIA) via GPS observations and ii. temporal variations of supraglacial lakes by on-site measurements.

Objective 4 constitutes a lithospheric study in the Aurora vent field at the western end of Gakkel Ridge (Fig.1.1). In order to find out where the vents mine heat to drive vigorous hydrothermal circulation, we will deploy ocean bottom seismometers and deep-ocean moorings to record microseismic activity around the vent location for the duration of one year and in parallel monitor the physical properties of its hydrothermal plume.

Polarstern will depart from Bremerhaven on 26 June. Upon arrival in Fram Strait we will first service the FRAM mooring array in eastern and central Fram Strait (see WSC in Fig.1.1). We shall then conduct the MIZ study north of Svalbard (marked by I-M-O in Fig.1). Here multi-platform, indisciplinary measurements will be carried out (see Fig.1.2). A short visit will be paid to the Aurora Vent field to deploy the seismometers and moorings. Subsequently, the MIZ work will be resumed. Finally, *Polarstern* will move to the Greenlandic Coast near the 79NG (see Fig. 1.1) in order to study the ocean-driven glacier retreat. While we have requested to recover three moorings in Scorsby Sound (East Greenland), we will most likely carry out this work during a separate expedition. Upon completion of the programmes there will be a direct transit back to Bremerhaven, where the expedition will end on 17 August.

2. PHYSICAL OCEANOGRAPHY

Wilken-Jon von Appen[1], Torsten Kanzow[1], Mario Hoppmann[1], Rebecca McPherson[1], Zerlina Hofmann[1], Simon Reifenberg[3], Hauke Becker[1], Matthias Monsees[1], Rainer Graupner[1], Normen Lochthofen[1], Janine Ludszuweit[1], Ilker Fer[2], Fiona Ellliot[2]
Not on board:
Maren Walter[3,] Marcel Nicolaus[1], Yusuke Kawaguchi[4], Tak Nose[4], Takuji Waseda[4], Jean Rabault[6], Gilbert Emzivat[5]

[1]DE.AWI
[2]NO.UIB
[3]DE.UNI-Bremen
[4]JP.UTOKYO
[5]NO.METNo
[6]FR.SHOM

Grant-No. AWI_PS131_07

Objectives

The physical oceanography group will carry out work in four distinct areas during the cruise. The objectives in the different areas are complementary but also partially independent.

Area 1 (FRAM): Long term monitoring of the WSC and in the Hausgarten observatory

The monitoring programme of the Atlantic Water (AW) inflow into the Arctic via the West Spitsbergen Current (WSC) started in 1997. ATWAICE will contribute to maintaining this long-standing time series observatory, as the AW inflow conditions drive the changing physical (and also biogeochemical and biological) properties of the Arctic Ocean. Hence, our key question is: How do the properties of the AW inflow change at one of the main Arctic Ocean gateways and how do changes influence the wider Arctic environment? What is the long-term evolution in the transport of those properties into the Arctic Ocean?

The Frontiers in Arctic Marine Monitoring (FRAM) Helmholtz infrastructure initiative has increased the ability to observe the temporal evolution of the coupled physical-chemical-biological system in the upper water column and troughout the water column to the sea floor. Continuing these interdisciplinary time series will allow for the evaluation of interannual variations in addition to shorter term interactions on mesoscale to seasonal timescales. Two main multidisciplinary time series locations are pursued in the framework of FRAM and its continuation: F4 site at 1,000 m water depth in the inflowing Atlantic Water boundary current (West Spitsbergen Current) and EG4 site at 1,000 m water depth in the outflowing Polar Water boundary current (East Greenland Current). By clearly being embedded in very different water masses representing end points of Arctic conditions, they will allow for a better prediction of what is to be expected in the Arctic Ocean.

Area 2 (MIZ): Ocean-sea ice coupling in the MIZ

This objective represents the major focus of ATWAICE related to key mechanisms of rapid Arctic sea ice decline and Arctic Amplification. These include processes affecting heat fluxes in the air-ice-ocean system, ocean mixed layer-halocline coupling, ice melt and ice edge dynamics in the MIZ. We posit that oceanic eddies, fronts and tidal mixing shape the sea ice distribution in the MIZ which leads to locally enhanced ice melting as well as to the generation of stratified areas with suppressed melting. These processes result in sea ice characteristics that can be distinguished by different gradients of sea ice floe size, concentration, roughness and thickness. Our study also aims to understand the complex physical-chemical-biological interactions that control biogeochemical cycling and ecosystem functioning. Our guiding questions in the MIZ are:

Q1: What are the pathways and processes in the inflow regions of warm AW to the Arctic Ocean that transport heat and nutrients to the sea ice and into the euphotic layer in the MIZ? Q2: How does the dynamic structure (stratification, mixing rates, (sub-)mesoscale activity) of the upper ocean change spatially from open ocean across the MIZ to the pack ice? How does it change seasonally with strongly varying atmospheric forcing? Q3: What is the fate of sea ice in the summer melting season? And how does it change over time as oceanic mixing and atmospheric fluxes change over time? Q4: How do the physical (sub-)mesoscale structures (fronts, ice-edge, eddies, etc.) and sea ice properties (e.g. melt ponds, light transmission) impact biological production?

Area 3 (79NG): Ocean impacts on marine-terminating glaciers in Northeast Greenland

In terms of Greenland, the North-East Greenland Ice Stream (NEGIS) system shows signs of significant ocean-driven thinning of its major outlet glaciers, the Nioghalvfjerdsfjorden Glacier (79NG) and Zachariæ Isstrøm (ZI). Ocean and ice-based studies will establish the trajectory of the NEGIS system. We aim to implement sustained monitoring capacities for investigating ocean-driven melt of the 79NG and ZI with the aim to answer the question: What are the sensitivities of present-day ocean-driven melt to changing environmental conditions at 79NG and ZI? Additionally, a comparison study at Scoresby Sund provides data on ocean-glacier coupling further south in Greenland.

Area 4 (Aurora): Plume monitoring at the Aurora vent field

The ultra-slow spreading Gakkel Ridge presents a source of chemical elements washed out by the hydrothermal fluids to the Arctic Ocean. Little is known about the plume’s temporal variability and its interaction with tectonic and oceanographic events (e.g. current reversals). We aim to cover a whole seasonal cycle of plume properties.

Work at sea

The cruise track will be oriented along the different planned mooring operations as outlined in Figure 2.1. We will operate a number of different instruments in the different areas:

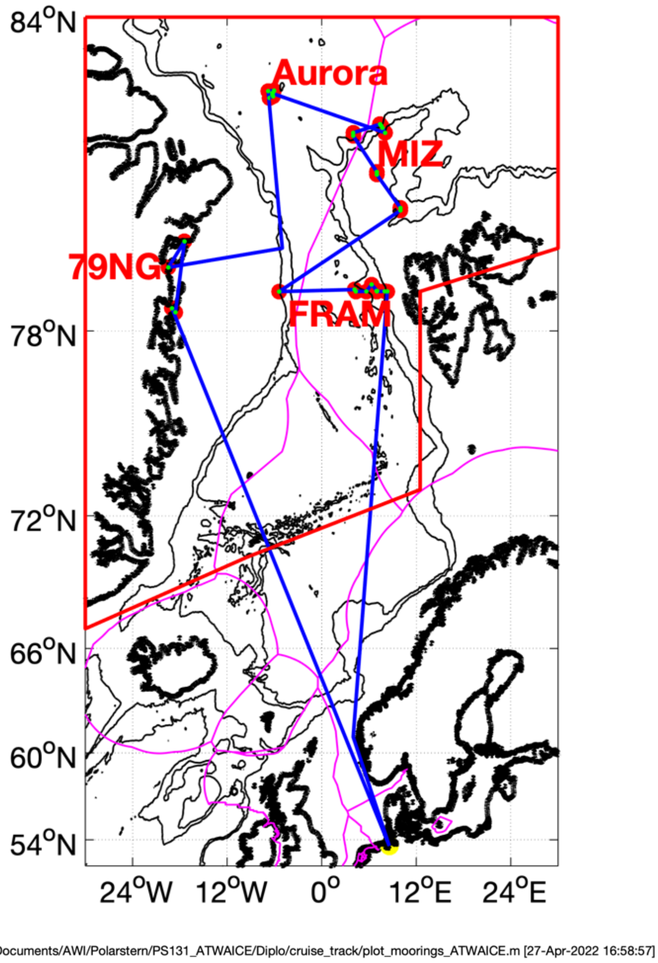


Figure 2.1: Locations of planned mooring operations (green dots) overlaid on the presumptive cruise track (blue). The general working area is outlined in red and EEZ boundaries are in magenta.

Mooring recoveries and deployments (areas 1, 2, 3, 4)

As listed in Table 2.1, we will recover 12 oceanographic moorings and deploy 25 moorings. These moorings generally contain observations for water temperature and salinity as well as current velocity. Additionally, some also target sea ice properties and biogeochemical/ biological parameters. Upper ocean physical-biological clusters (areas 1, 2) will have an instrument setup similar to what has been used at HG-IV and F4 in eastern Fram Strait since 2016 (e.g. PS99.2/PS107/PS114/PS121/PS126). Three moorings will also include winches (areas 1, 2) to measure profiles in the top 100 m of the water column. Furthermore, a mooring will be equipped with a 30 m plastic tube (area 2) at its top that can get hit by sea ice without being destroyed; this allows the sensors to be placed closer to the ocean surface than would otherwise be possible. In order to maintain the microbial and biogeochemical observations of the FRAM observatory, five sediment traps and two automated water samplers will be exchanged at three selected long-term stations of LTER HAUSGARTEN. A mooring in front of the 79NG (area 3) will be equipped with an acoustic modem that allows to retrieve the data in case the mooring hardware cannot be recovered due to fast ice conditions. Miniature Autonomous Plume Recorders (MAPR) will be placed near the vent site (area 4).

Tab. 2.1: List of planned mooring operations

No.	Name	Type	Longitude			Latitude			Depth	Top
			Degrees	Minutes		Degrees	Minutes		Meters	Meters
1	F2-20/21	Mooring recovery and deployment	8	19.84	E	79	0.02	N	785	20
2	F3-19/20	Mooring recovery and deployment	7	59.84	E	79	0.12	N	1075	30
3	F4-20/21	Mooring recovery and deployment	7	0.03	E	79	0.01	N	1218	30
4	F4-S-5/6	Mooring recovery and deployment	6	57.81	E	79	0.71	N	1222	10
5	F4-W-3/4	Mooring recovery and deployment	7	2.14	E	79	0.70	N	1236	10
6	F4-OZA-2/3	Mooring recovery and deployment	6	19.96	E	79	9.99	N	1418	50
7	F5-19/20	Mooring recovery and deployment	5	40.12	E	79	0.02	N	2100	30
8	HG-IV-FEVI-42/44	Mooring recovery and deployment	4	19.92	E	79	0.00	N	2542	30
9	Lander-2021/2022	Lander recovery and deployment	4	10.47	E	79	2.73	N	2564	2564
10	HG-EGC-7/8	Mooring recovery and deployment	5	23.78	W	78	59.75	N	996	30
11	Y1-1	Mooring deployment; Sea ice buoys deployment and recovery	10	0.00	E	80	48.00	N	1018	20
12	Y2-1	Mooring deployment	10	0.00	E	80	51.00	N	1010	20
13	Y3-1	Mooring deployment; Sea ice buoys deployment and recovery	7	0.00	E	81	30.00	N	577	10
14	Y4-1	Mooring deployment	7	0.00	E	81	33.00	N	585	20
15	Y5-1	Mooring deployment; Sea ice buoys deployment and recovery	4	0.00	E	82	12.00	N	2456	20
16	Y6-1	Mooring deployment	4	0.00	E	82	15.00	N	2717	20
17	Y5-2	Mooring deployment	7	25.00	E	82	23.80	N	2460	20
18	Y6-2	Mooring deployment	7	33.00	E	82	22.20	N	2087	20
19	Y7-1	Mooring deployment	7	43.00	E	82	20.00	N	1541	20
20	Y8-1	Mooring deployment	8	3.00	E	82	15.00	N	801	20
21	Aurora-1	Mooring deployment	6	15.32	W	82	53.83	N	3900	50
22	Aurora-2	Mooring deployment	6	19.00	W	82	53.75	N	4040	50
23	OBS-A1	OBS deployment	6	25.00	W	82	53.50	N	4200	4200

No.	Name	Type	Longitude			Latitude			Depth	Top
			Degrees	Minutes		Degrees	Minutes		Meters	Meters
24	OBS-A2	OBS deployment	6	10.00	W	82	54.50	N	4000	4000
25	OBS-A3	OBS deployment	6	10.00	W	82	51.00	N	4800	4800
26	OBS-A4	OBS deployment	6	37.50	W	82	49.50	N	4500	4500
27	OBS-A5	OBS deployment	6	2.50	W	82	56.50	N	4300	4300
28	OBS-A6	OBS deployment	6	47.50	W	82	56.00	N	4000	4000
29	79N2-3	Mooring deployment	19	27.83	W	79	34.01	N	476	100
30	79N4-2	Mooring deployment	17	24.56	W	80	8.92	N	172	100
31	79N9-1	Mooring deployment	18	33.50	W	78	29.00	N	420	100
32	79N10-1	Mooring deployment; Sea ice buoy deployment	19	0.00	W	78	35.00	N	600	100

CTD-rosette profiles (areas 1, 2, 3, 4)

At all mooring locations we will perform CTD stations. We will also run multiple CTD sections across the MIZ (area 2) and in front of the outlet glaciers (area 3). The CTD will be equipped with dual temperature, conductivity, and oxygen sensors as well as single chlorophyll fluorescence, transmissivity, CDOM, and PAR sensors. Furthermore, two lowered ADCPs (upward and downward looking), a SUNA nitrate sensor, and an underwater vision profiler (UVP) will be mounted to the rosette. We will also attach SBE37 microcats and SBE56 temperature loggers to the rosette for a few casts to perform *in-situ* sensor calibration casts. Water samples from the CTD rosette will be run on the salinometer and oxygen titration rig to support the calibration/data processing of the conductivity and oxygen sensors, respectively.

Underway temperature/salinity/velocity (entire cruise)

Throughout the cruise we will operate the underway thermosalinograph to get surface ocean hydrographic properties and we will operate the 150 kHz RDI OceanSurveyor vessel mounted ADCP.

Triaxus (area 2)

We will tow the Triaxus towed ocean profiler of the AWI (topAWI) along a number of sections from medium concentration pack ice into the open ocean. For this a depressor system will be employed whose purpose is to pull the towing cable straight down behind the ship’s stern such that the towing cable will not become entangled in sea ice. The sections will be 100–200 km long and cover either the top 100 m or the top 300 m of the water column at high (sub-kilometer) spatial resolution. Sensor based physical, biogeochemical, biological, and optical measurements will be undertaken, among others with a SBE911+ system mounted to the Triaxus. In case the Triaxus should not be operational or the sea ice conditions should prohibit its operation, similar sections will be occupied with the Teledyne Oceanscience underway CTD (UCTD) system.

Microstructure measurements (area 2)

We will deploy a glider equipped to measure microstructure temperature/salinity/shear in the beginning of the time in area 2. It will occupy repeat sections from the open water to the ice edge which in this context is defined as the location where the glider pilot deems the safety of the vehicle to be in danger. The glider will be recovered at the end of the time in area 2. We will also occupy repeat microstructure profiling stations that resolve the tidal cycle either from sea ice floes, from a zodiac, or from *Polarstern*, depending on ice conditions.

GPS drifters (area 2)

We will deploy a number of GPS drifters that are drogued to 30 cm water depth and some of those will also be placed on sea ice floes. This will provide Lagrangian trajectories of surface water masses and ice floes, respectively, to maintain a coordinate system for the interpretation of the data to be collected both in a Lagrangian and in an Eulerian framework.

Sea ice based in-situ and autonomous observations (area 2)

Buoy deployment on main ice stations: At the beginning of the MIZ work programme, up to three representative ice floes (RIFs) will be identified, where several hours-long ice stations will be conducted for intensive sampling. During these initial ice stations, a large number of autonomous systems will be installed to measure atmospheric conditions, ice mass balance, surface energy fluxes and upper-ocean properties on a main buoy site. During revisits of the RIFs, the various manual samplings will be repeated and the condition of the floes (in particular also the condition of the different instruments) will be documented. During the final visit at the end of the expedition, the instruments and their data will be recovered.

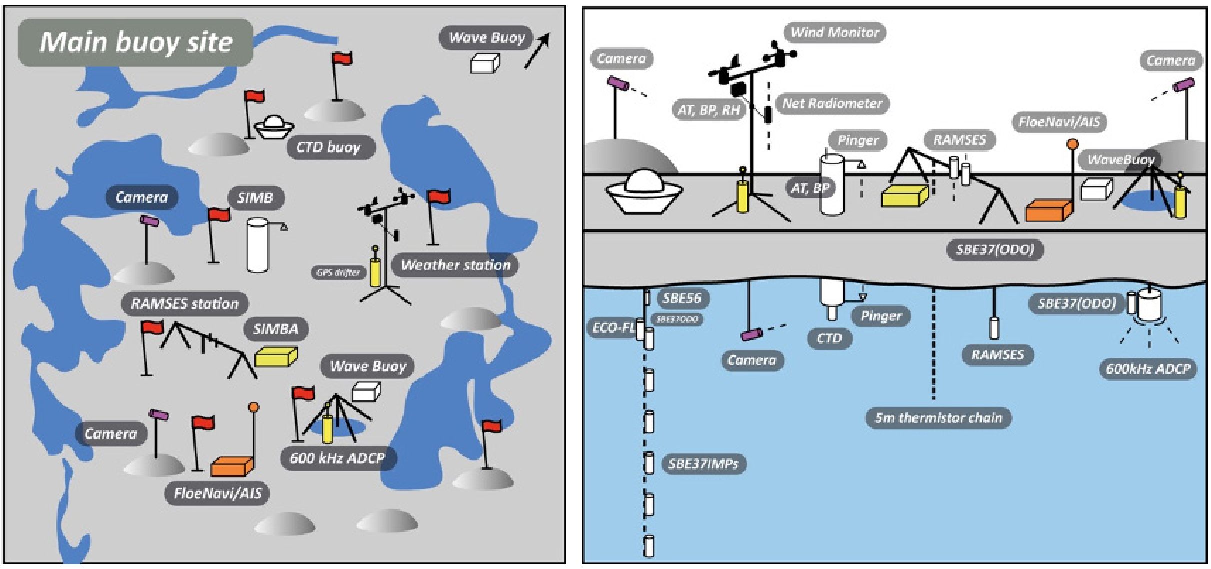


Fig. 2.2: Left panel: Exemplary sketch of instrument setup on the main buoy site of the first floe (RIF1). RIF2 and RIF3 have slightly different setups, since the number of instruments is limited. Right panel: Schematic of instrument setup on the main buoy site (side view).

Wider Distributed Network: The instruments and measurements on the RIFs will be complemented by a large number of GPS and wave buoys that will be distributed along the main transects through the MIZ. These buoys will be placed on individual ice floes or in the water using the helicopter, zodiac or mummy chair, and report their data in near-real time via the iridium satellite network. When time allows, these deployments will be accompanied by sampling from other groups, e.g. CTD profiles and electromagnetic ice thickness sounding.

Barometric pressure in the Arctic: A total of 5 SVP-type GPS drifters with barometric pressure sensors will be distributed along the cruise track, including the Aurora vent field and East Greenland, in order to obtain additional barometric pressure measurement in the Arctic Ocean.

Sea ice mooring and CTD/LADCP deployments (area 3)

We will deploy one mooring via helicopter from a fast ice floe as it is expected that *Polarstern* cannot enter the ice mélange in front of Zachariæ Isstrøm. In that area we will also deploy a lightweight CTD/LADCP system from an ice floe to obtain profiles of the near bottom flow into the glacier's cavity of warm Atlantic Water in approximately 400 m water depth.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

This expedition is supported by the Helmholtz Research Programme "Changing Earth – Sustaining our Future" Topic 2, Subtopic 2.1.

In all publications based on this expedition, the Grant No. AWI_PS131_07 will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

3. SEA ICE GEOPHYSICS AND REMOTE SENSING

Christian Haas[1], Gunnar Spreen[2], Mara Neudert[1], Lena Buth[1], Hannah Niehaus[2], Victor Lion[3], Jan Rohde[1]

[1]DE.AWI, [2]DE.UNI-Bremen, [3]DE.CAU

Grant-No. AWI_PS131_02

Objectives

In line with the main objectives of the ATWAICE/PS131 cruise (see Chapter 1), our main objective is to study ice melt processes across the MIZ in dependence of oceanic and atmospheric boundary layer conditions. Oceanic eddies, fronts and tidal mixing shape the sea ice distribution in the MIZ which leads to locally enhanced ice melting as well as to the generation of stratified areas with suppressed melting. These processes result in sea ice characteristics that can be distinguished by different gradients of sea ice floe size, concentration, roughness and thickness. Our activities are therefore highly interdisciplinary and collaborative, and will be carried out particularly closely with the oceanographic buoy and under-way observations (Chapter 2).

There have been numerous studies of ice melt of individual floes (e.g., Sirevag et al., 2011), but up to now there are only few observations of ice thinning across the MIZ (e.g., Rabenstein et al. 2010; Provost et al., 2017; Duarte et al., 2020), in relation to ocean heat, current or wave, or melt pond gradients between the open water and close pack ice zones. These were not even achieved during the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) in 2020 (Nicolaus et al., 2022; Rabe et al., 2022).

The presence of melt ponds on the surface of Arctic sea ice significantly reduces its albedo, which has implications for the energy and mass budget of the ice and for primary productivity in the upper ocean, and accelerates melt by way of ice-albedo feedback processes. Melt pond coverage is also indicative of the amount of surface melt and freshwater released to the ocean which contributes to upper ocean stratification.

Satellite remote sensing is an important complement to *in-situ* field studies, and can provide information over longer time periods and larger regions than feasible with direct observations. We will therefore use extensive remote sensing data to improve and validate algorithms for retrievals of ice concentration, thickness, floe size, melt pond coverage, and ice drift. The satellite retrieval of parameters, such as the spectral behaviour of sea ice and melt ponds, relies on spectral information, which requires a retrieval of their optical properties (e.g. König et al., 2019; Malinka et al., 2018). ATWAICE provides unique opportunities for microwave and optical field measurements in the MIZ. They will also support atmospheric corrections and help to calibrate and validate remote sensing products of sea ice albedo, melt pond depth and distribution, as well as tracking of (individual) drifting floes.

Apart from studying the MIZ, our objectives are to obtain opportunistic ice thickness and melt pond data during the transits to and from the Aurora vent field (Chapter 7) and the 79 North Glacier (Chapter 2 und 11) to continue our long-term ice thickness observations in the Arctic Ocean and Transpolar Drift (e.g., Haas et al., 2008; Belter et al., 2021).

Work at sea

In-situ observations

We plan to carry out extensive *in-situ* observations during short and long ice stations during the transects across the MIZ (Figure 3.1). The long ice stations will visit four ice floes which will be revisited at least three times during the three-to-four weeks observational period. Ice floes will be equipped with various autonomous systems to measure ice mass balance, surface energy fluxes, and under-ice stratification and heat flux (see Chapter 2).

On long ice stations up to 6 hours long we will carry out optical characterization of melt ponds and adjacent snow and ice. This includes high accuracy spectroradiometer measurements at several locations and along transects as well 2-D hyperspectral imaging of larger surface areas. Also long (several kilometers) electromagnetic ice thickness and melt pond depth surveys will be carried out. Few ice cores will be taken occasionally to characterise ice temperature and salinity profiles.

Short ice stations will be carried out on small ice floes to which the *Polarstern* cannot be anchored. Those ice floes will be reached by helicopter or zodiac. Short ice thickness surveys will be carried out by electromagnetic sounding, and upper-ocean salinity, temperature, and turbulence profiles will be obtained by CTD or MSS sondes at the floe edge or from the zodiac.

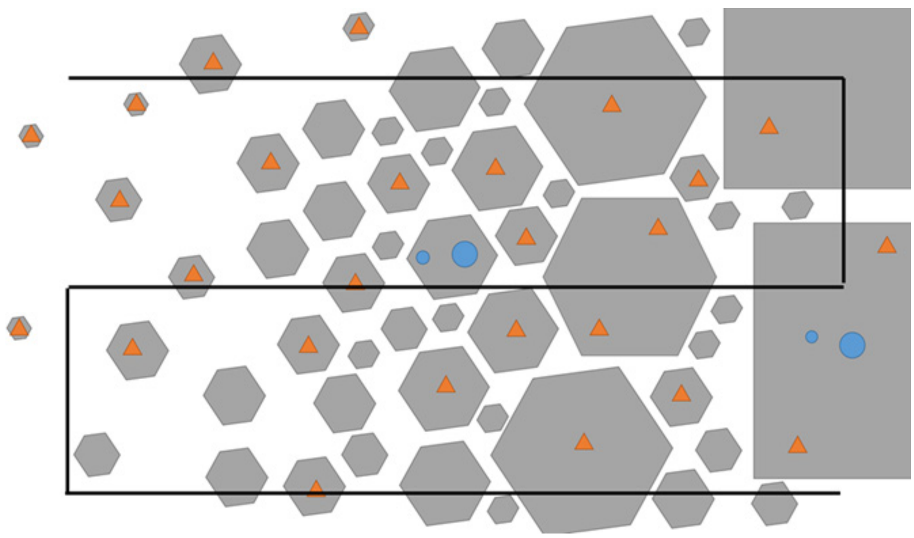


Fig. 3.1: Sketch showing the floe size gradients across the MIZ and the three transects which will revisit four ice floes with different sizes and thicknesses (blue circles). In addition, a large number of ice floes will be equipped with autonomous sensor systems to obtain continuous data during the complete study period.

Ice-tethered platforms (buoys)

A set of autonomous ice tethered platforms (buoys) will be deployed to monitor ice mass balance, surface energy fluxes, upper-ocean stratification and heat flux, and ice floe drift including eddies penetrating into the MIZ. More information is provided in Chapter 2 (Oceanography).

Helicopter surveys

We will carry out extensive, repeat melt pond, surface roughness, surface temperature, and ice thickness surveys with *Polarstern's* helicopters over distances of up to 80 nautical miles and across the MIZ to characterise large scale gradients and temporal change in relation to varying oceanic conditions. Melt pond coverage and floe size will be measured with standard downward-looking DSLR cameras. An airborne laser scanner (ASL) will be used to survey ice surface roughness and to obtain additional melt pond information. A thermal infrared imaging system will provide surface temperatures and derived floe size and melt pond information. Ice thickness will be observed by means of electromagnetic (EM) induction sounding using an EM Bird.

We plan to carry out as many surveys as possible to get the best possible temporal resolution of our time series observations. Surveys will also follow the same ice fields and floes by overflying the buoys used to mark individual ice floes visited during ice stations.

Underway measurements

In order to better resolve the ice thickness variability and gradients and their temporal change across the MIZ, we will use an EM sounder deployed by the bow crane (Sea Ice Monitoring System SIMS) to measure ice thickness continuously along the ship's track, in conjunction with the underwater topAWI towed CTD system. This requires that during the numerous transects across the MIZ the ship travels along straight, representative tracks without avoiding ice by circumnavigating it.

In addition, we will operate microwave radiometers and an infrared/visual camera looking at the ice in collaboration with the atmosphere water vapor observations (Chapter 8), a PANOMAX camera system, and a laser scanner continuously from the ship, and will carry out visual ice observations from the bridge.

Satellite remote sensing

We will use various satellite radar (at least Sentinel 1 SAR, TerraSAR-X, ASCAT), altimetry (at least CS2, ICESat-2), optical (at least Sentinel 2 and 3 and MODIS), and microwave observations (at least AMSR2) to better characterise the largescale variability of ice concentration, floe size, melt pond coverage, and ice drift across the MIZ and their temporal change. Many data will be received directly on board and will support our planning of ice stations, airborne surveys, and ship transects. We closely work with DLR for dedicated TerraSAR acquisitions.

Preliminary (expected) results

We expect to obtain a full characterization of ice conditions across the MIZ and their regional and temporal variation and change. These, together with our atmospheric and oceanic measurements, will support a better understanding of summer ice melt processes in the MIZ, and will help to better model and predict the fate of sea ice in the ever growing MIZ.

We will obtain results on two different scales:

1. Floe scale: By means of our repeat *in-situ* and continuous autonomous measurements we can study melt processes and the interplay of under-ice stratification and turbulence under individual ice floes.

2. Regional scale across the MIZ: By means of our airborne, ship-based, and satellite measurements we can upscale the results of the *in-situ* measurements and characterise interrelated sea ice and oceanic gradients across the MIZ, to better understand the processes from initial ice break up and melting to the complete disappearance of the last ice.

In addition, through repeat visits of the same ice we can improve understanding of melt pond evolution and drainage.

Finally, our observations will help improve the interpretation of satellite data and the development of new retrieval algorithms, e.g., to derive melt pond sizes distribution or to track the movement of individual floes in the MIZ to study the pond evolution using Sentinel 1 and 2 data.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied. Buoy data will be available in near-real time through the online portal www.meereisportal.de, and will be embedded into different international data bases, including the International Arctic Buoy Programme (IABP).

This expedition was supported by the Helmholtz Research Programme "Changing Earth – Sustaining our Future" Topic 2, Subtopic 2.1.

In all publications based on this expedition, the Grant No. AWI_PS131_02 will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

References

Belter HJ, Krumpen T, von Albedyll L, Alekseeva TA, Birnbaum G, Frolov SV, Hendricks S, Herber A, Polyakov I, Raphael I, Ricker R, Serovetnikov SS, Webster M, and Haas C (2021). Interannual variability in Transpolar Drift summer sea ice thickness and potential impact of Atlantification, The Cryosphere, 15, 2575–2591, https://doi.org/10.5194/tc-15-2575-2021.

Duarte P, Sundfjord A, Meyer A, Hudson SR, Spreen G, & Smedsrud LH (2020). Warm Atlantic water explains observed sea ice melt rates north of Svalbard. Journal of Geophysical Research: Oceans, 125, e2019JC015662. https://doi.org/10.1029/2019JC015662

Haas C, Pfaffling A, Hendricks S, Rabenstein L, Etienne J-L, Rigor I (2008). Reduced ice thickness in Arctic Transpolar Drift favors rapid ice retreat, Geophys. Res. Lett., 35, L17501.

Nicolaus M, Perovich D, Spreen G, Granskog M, Albedyll L, Angelopoulos M, Anhaus P, Arndt S, Belter H, Bessonov V, Birnbaum G, Brauchle J, Calmer R, Cardellach E, Cheng B, Clemens-Sewall D, Dadic R, Damm E, Boer G, Demir O, Dethloff K, Divine D, Fong A, Fons S, Frey M, Fuchs N, Gabarró C, Gerland S, Goessling H, Gradinger R, Haapala J, Haas C, Hamilton J, Hannula H-R, Hendricks S, Herber A, Heuzé C, Hoppmann M, Høyland K, Huntemann M, Hutchings J, Hwang B, Itkin P, Jacobi H-W, Jaggi M, Jutila A, Kaleschke L, Katlein C, Kolabutin N, Krampe D, Kristensen S, Krumpen T, Kurtz N, Lampert A, Lange B, Lei R, Light B, Linhardt F, Liston G, Loose B, Macfarlane A, Mahmud M, Matero I, Maus S, Morgenstern A, Naderpour R, Nandan V, Niubom A, Oggier M, Oppelt N, Pätzold F, Perron C, Petrovsky T, Pirazzini R, Polashenski C, Rabe B, Raphael I, Regnery J, Rex M, Ricker R, Riemann-Campe K, Rinke A, Rohde J, Salganik E, Scharien R, Schiller M, Schneebeli M, Semmling M, Shimanchuk E, Shupe M, Smith M, Smolyanitsky V, Sokolov V, Stanton T, Stroeve J, Thielke L, Timofeeva A, Tonboe R, Tavri A, Tsamados M, Wagner D, Watkins D, Webster M, Wendisch M. 2022. Overview of the MOSAiC expedition – Snow and sea ice. Elementa Science of the Anthropocene 9. https://doi.org/10.1525/elementa.2021.000046.

König M, Hieronymi M and Oppelt N 2019: Application of Sentinel-2 MSI in Arctic Research: Evaluating the Performance of Atmospheric Correction Approaches Over Arctic Sea Ice. Front. Earth Sci., 7, doi:10.3389/feart.2019.00022.

Malinka A, Zege E, Istomina L, Heygster G, Spreen G, Perovich D, and Polashenski C(2018). Reflective properties of melt ponds on sea ice. The Cryosphere, 12, 1921–1937. doi:10.5194/tc-12-1921-2018

Provost C, Sennechael N, Miguet J, Itkin P, Rösel A, Koenig Z, Villacieros-Robineau N, and Granskog MA (2017), Observations of flooding and snow-ice formation in a thinner Arctic sea-ice regime during the N-ICE2015 campaign: Influence of basal ice melt and storms, J. Geophys. Res. Oceans, 122, 7115–7134, doi:10.1002/2016JC012011

Rabe B, Heuze C, Regnery J, Aksenov Y, Allerholt J, Athanase M, Bai Y, Basque C, Bauch D, Baumann TM, Chen D, Cole ST, Craw L, Davies A, Damm E, Dethloff K, Divine DV, Doglioni F, Ebert F, Fang Y-C, Fer I, Fong AA, Gradinger R, Granskog MA, Graupner R, Haas C, He H, He Y, Hoppmann M, Janout M, Kadko D, Kanzow T, Karam S, Kawaguchi Y, Koenig Z, Kong B, Krishfield RA, Krumpen T, Kuhlmey D, Kuznetsov I, Lan M, Lei R, Li T, Torres-Valde´ s S, Lin L, Lin L, Liu H, Liu N, Loose B, Ma X, MacKay R, Mallet M, Mallett RDC, Maslowski W, Mertens C, Mohrholz V, Muilwijk M, Nicolaus M, O'Brien JK, Perovich D, Ren J, Rex M, Ribeiro N, Rinke A, Schaffer J, Schuffenhauer I, Schulz K, Shupe MD, Shaw W, Sokolov V, Sommerfeld A, Spreen G, Stanton T, Stephens M, Su J, Sukhikh N, Sundfjord A, Thomisch K, Tippenhauer S, Toole JM, Vredenborg M, Walter M, Wang H, Wang L, Wang Y, Wendisch M, Zhao J, Zhou M, Zhu J, Laukert G. (2022). Overview of the MOSAiC expedition: Physical oceanography. Elementa: Science of the Anthropocene 10(1). DOI: https://doi.org/10.1525/elementa.2021.00062

Rabenstein L, Hendricks S, Martin T, Pfaffhuber A, Haas C (2010). Thickness and surface-properties of different sea-ice regimes within the Arctic Trans Polar Drift: data from summers 2001, 2004 and 2007, J. Geophys. Res., 115, C12059.

Sirevaag A, de la Rosa S, Fer I, Nicolaus M, Tjernström M, and McPhee M G (2011): Mixing, heat fluxes and heat content evolution of the Arctic Ocean mixed layer, Ocean Sci., 7, 335–349, https://doi.org/10.5194/os-7-335-2011.

4. VERTICAL TURBULENT AEROSOL PARTICLE TRANSPORT ABOVE OPEN WATER AND ICE IN THE CENTRAL ARCTIC DURING SUMMERTIME (APAICA) – AEROSOL PARTICLE SOURCES AND TRANSFORMATION IN THE ARCTIC MARINE BOUNDARY LAYER

Arun Babu Suja[1], Phlipp Oehlke[1], Sabine Lüchtrath[2]
Not on board: Birgit Wehner[1], Thomas Müller[1], Laurent Poulain[1], Maik Merkel[1], Holger Siebert[1], Heike Wex[1], Andreas Held[2]

[1]DE.TROPOS
[2]DE.TU-BERLIN

Grant-No. AWI_PS131_04

Outline

Aerosol particles are a key component of the Arctic climate system. Depending on their optical properties, their ice nucleating properties, and thus, their ability to form and modify Arctic clouds, aerosol particles change the radiation budget. Therefore, it is important to identify and quantify Arctic particle sources and sinks, including vertical transport, and to characterise their optical properties as well as their impact on cloud formation. However, there have only been very few surface-atmosphere particle flux measurements above open water and ice in the Central Arctic, and data on physical and chemical properties of Arctic aerosol particles are scarce. This project will focus on the turbulent flux of aerosol particles and on black carbon as well as ice nucleating particles (INP) in the air and ocean water.

Turbulent particle fluxes

To date, turbulent particle flux measurements in the Arctic and Antarctic regions have been made over snow and rock cover in Antarctica (Grönlund et al., 2002), over the Nansen Ice Sheet in Antarctica (Contini et al., 2010), over unbroken sea ice in the Canadian Hudson Bay (Whitehead et al., 2012), and in the Central Arctic Ocean (Nilsson and Rannik, 2001; Held et al., 2011a, b). Saylor et al. (2019) point out that there are not enough observations to evaluate the validity of parameterizations for particle dry deposition over snow and ice surfaces used in models, and local particle emission strengths are not well constrained. One local particle emission source are open leads, which have been described as potential sources of atmospheric particles for the first time by Scott and Levin (1972). Nilsson and Rannik (2001) measured turbulent particle fluxes by eddy covariance in the high Arctic over the open sea and over the pack ice. However, the measurement footprints over the pack ice were generally large, and Nilsson and Rannik (2001) acknowledge that most measurements were influenced by a mix of open lead and ice surfaces. Using eddy covariance and gradient measurements on the edge of an ice floe, Held et al. (2011a, b) observed a larger fraction of net emission aerosol fluxes over open leads compared to mostly net deposition over the pack ice. However, the measured aerosol fluxes could not fully explain the observed changes in particle number concentration. Thus, it is extremely important to better quantify and constrain the contribution of vertical turbulent particle fluxes and other processes to the local particle number budget in the Central Arctic boundary layer.

Black carbon

Black carbon (BC) is the most efficient atmospheric absorber of visible light (Bond et al., 2013). BC-containing particles in the Arctic can affect the radiation balance in various ways. BC particles warm the atmosphere directly by absorption of solar radiation (Haywood and Shine, 1995), and affect distribution, microphysical properties and lifetime of clouds through indirect and semidirect effects (Twomey, 1974, Ackerman et al., 2000; Jacobson, 2012; Bond et al., 2013). The mixing state plays an essential role in these processes. Studies on the mixing state in Arctic regions have been carried out by e.g. Raatikainen (2015), Zanatta (2018), and Abbatt (2019). Furthermore, BC can darken the surface and enhance absorption of radiation when deposited on snow (Quinn et al., 2011). In the airborne state, a coating on BC particles can lead to an increase in light absorption (Schwarz 2008) and also affect the ability of how well they can act as CCN (Cloud Condensation Nuclei) (e.g., Maskey et al., 2017). Motos et al. (2019) showed that externally mixed soot particles in fog with supersaturations between 0.03 % and 0.06 % do no act as CCN, while soot particles with a thick coating show a similar behaviour as soot free particles. Overall, the wet deposition for black carbon is slower than for other particles (Dlugi, 1989). Moreover, Ding et al. (2019) depicted the influence of soot on the fog formation through feedback mechanisms. Measurements of the undissolved part of refractory black carbon (rBC) in low-salinity water have been done (Bisiaux et al. 2011; Torres et al. 2014). Ohata et al. (2013) showed that rBC can be detected with modern methods (Single Particle Soot Photometer, SP2) even at low concentrations in rainwater, and measurements of soot in cloud droplets were shown in Schroder et al. (2015). There is only sparse information on the deposition of BC in the ocean (Jurado et al., 2008). Thus, collocated measurements of airborne rBC particles and rBC in fog droplets and in the ocean would improve our understanding of the mechanisms of the magnitude of rBC deposition into the ocean. However, no measurements have yet been carried out with the SP2 for ocean water with high salinity. A cross-sensitivity of the SP2 to sea salt was found in Zanatta et al. (2021) for Arctic snow samples. A desalination method was described by Zeppenfeld et al. (2020) but was not used to examine the rBC content of ocean water so far.

Ice nucleating particles

Ice nucleating particles (INP) are needed for the formation of primary ice crystals in supercooled clouds down to temperatures of ~ –38° C, the mixed phase cloud regime. The abundance of INP in the atmosphere has therefor a large effect on cloud glaciation, which then, in turn, has an effect on the cloud radiative properties, lifetime and precipitation formation. Sources for atmospheric INP, the INP abundance and possible parameterizations describing the latter have become an intensely researched field in the past years. It becomes clearer that INP concentrations at remote marine locations are comparably low (McCluskey et al., 2018a,b; Welti et al., 2020) while mineral dust particles and also biogenic particles emitted from continents contribute large fractions of the overall atmospheric INP load (Welti et al., 2020; Gong et al., 2020a, b). Based on airborne measurements from different campaigns, it was observed that mixed phase clouds in the Arctic contain larger fractions of supercooled liquid droplets, compared to clouds in midlatitudes and the tropics (Costa et al., 2017). This was assumed to originate in low INP concentrations. However, newer ground-based measurements from the Arctic show that there is a pronounced annual cycle in INP concentrations, with high concentrations observed in spring and summer months (Wex et al., 2019, Creamean et al., 2018; Tobo et al., 2019; Šantl-Temkiv et al., 2019). Sources for these cannot easily be attributed, and marine as well as terrestrial Arctic sources were suggested (Creamean et al., 2018; Wex et al., 2019). For INP active at –25° C, collected in the Canadian Arctic (in Alert) in spring, Si et al. (2019) found that INP concentrations correlated with mineral dust tracers and suggested long range transport and origin in the Gobi Desert. On the other hand, during an aircraft campaign conducted from Northern Greenland (Villum Research Station) in spring, high INP concentrations at temperatures above –15° C were observed when flights took place at low altitudes over open leads and polynyas (Hartmann et al., 2020). For these INP, collocated measurements indicated a local marine source. In another campaign, a comparison was done for INP concentrations determined simultaneously for the Arctic ocean water and air, and airborne concentrations were orders of magnitude above those that could be expected if sea spray was the major contributor to atmospheric INP, while, no clear source apportionment could be done, although a large number of parameters was tested (Hartmann et al., 2021).

Objectives

Overall, it is important to improve our understanding of Arctic clouds, particularly mixed phase clouds, and their role in the effect of the observed strong Arctic warming (known as Arctic Amplification, Serreze and Barry, 2011), where these clouds are included in a complex web of interactions and feedbacks (Morisson et al., 2012). The cold and mixed phase in these clouds plays an important role, so sources and abundancies of INP need to be understood much better and for that, more detailed studies are needed (Solomon et al., 2018).

During the *Polarstern* cruise PS131 we aim to contribute to a better understanding of "Ocean-sea ice - atmosphere coupling in the MIZ and controls on the ecosystem" by addressing the following research questions:

- What are magnitude and sign of turbulent particle fluxes and how do they vary for different types of surface and meteorological conditions?
- What are the contributions of (i) local particle emission from the ocean and (ii) new particle formation (NPF) to the entire budget of Arctic marine boundary layer (MBL) aerosol concentration? What are the controlling factors of these processes?
- How large are BC concentrations in the air, fog and ocean?
- How is BC in surface water linked to atmospheric BC and what is the role of the mixing state for deposition?
- What are the major sources for INP in the Arctic MBL, and particularly to what extent does the ocean contribute INP to the Arctic atmosphere?

Work at sea

Our measurement strategy onboard covers continuous aerosol sampling and measurement activities as well as additional intensive measurements during selected periods on station, when calm conditions allow the setup of instruments at the frontal outrigger and at the crane.

For continuous measurements of physical and chemical aerosol parameters, a laboratory container (Aerosol-Container) equipped with instrumentation will be placed at the first deck of the ship just above the bridge (Peildeck). Continuous Aerosol-Container measurements include particle number size distributions from 10 nm to 10 µm using a combination of SMPS (Scanning Mobility Particle Sizer) and APS (Aerodynamic Particle Sizer). Optical properties, such as scattering and absorption coefficients will be continuously measured by MAAP (Multiangle Absorption Photometer), Aethalometer AE33, Nephelometer and a low flow absorption photometer (STAP or MA200). The mixing state and size distribution of airborne BC-containing particles will be analyzed by the SP2 (Single Particle Soot Photometer). In addition, a high-volume filter sampler will be installed on the roof of the container to collect aerosol particles (PM10) at a sampling regime of 24 h during the entire cruise to provide information on the total particles mass concentration and the chemical composition of the aerosol particles (organic and elemental carbon, OC/EC, and water-soluble ions) as well as for the INP analysis to provide a general coverage of INP concentrations throughout the whole cruise. Sea water samples will be taken twice per day throughout the cruise from the onboard sea water pipeline. All filters and water samples will be stored frozen on the ship for offline analysis at TROPOS after the campaign.

The Arctic summer is characterised by the frequent occurrence of fog events. During these events, fog and cloud water will be collected on top of the aerosol container with a fog water sampler. Fog water samples will be stored frozen right after sampling and analyzed offline after the campaign for BC and its mixing state, INP concentration and basic chemical composition (water soluble ions and water-soluble organic carbon).

Filter samples for INP analysis will also be collected at the frontal outrigger, and stored frozen on the ship for analysis after the campaign. These INP concentration measurements will give evidence about a possible marine origin of the INP. Sea water samples will be collected from the onboard sea water pipeline for INP analysis during the times when filters for INP analysis are taken at the frontal outrigger.

During intensive measurement periods of several hours, when the ship is drifting close to the ice edge or moving slowly through open water, vertical particle fluxes will be measured and estimated by two methods in parallel, the eddy covariance method and the gradient method. For eddy covariance, collocated measurements of the turbulent wind vector and aerosol number concentration will be carried out using an ultrasonic anemometer, a fast mixing-type condensation particle counter (MCPC) and a standard laminar flow-type CPC placed in a temperature-stabilized box (AerosolCube 1) at the frontal end of the outrigger. A motion package attached to the sonic will allow for proper estimating the vertical wind component necessary for the covariance. For the gradient method, another MCPC in combination with a 1D turbulence probe (AerosolCube 2) will be fixed at the bow crane and moved up and down for profiling particle concentrations in the lower 12 m above the sea surface. AerosolCube 2 can also be fixed at a certain height allowing for particle measurements at two different heights. During these intensive particle measurements from the frontal outrigger, the vessel should be facing into the mean wind direction in order to minimize flow distortion and any influence of ship exhaust, which would be detected by strongly elevated particle number concentrations.

Preliminary (expected) results

Parallel sampling of ocean water, particulate matter, and fog and cloud water combined with particle flux measurements will provide a unique opportunity to better understand ocean - sea ice - atmosphere interactions in the Arctic. We expect to collect a unique data set of combined eddy covariance and gradient measurements of turbulent particle exchange fluxes between the atmosphere and various surface types (e.g. open water, open leads, ice floes, ice edge) in the Arctic MIZ. Previous particle flux measurements from an ice floe in the central Arctic Ocean during ASCOS 2008 could not fully explain the observed changes in aerosol number concentration, and measurements taken during PS131 will provide the opportunity to investigate the contribution of vertical particle fluxes to the aerosol budget in the MIZ over various surface types. Regarding BC-containing particles, there is only sparse information on the deposition of BC to the ocean. Online measurements of BC and its mixing state using the SP2 combined with offline measurements of these parameters in sea water and fog water samples will help to identify transport pathways of BC particles in the Arctic MIZ. For INP, previous studies indicated local marine sources but source apportionment is very difficult. Analysis of sea water, aerosol and fog water samples will show how INP in these compartments are connected, and, together with other analyses done in this study, will help to reveal if the ocean can be a major contributor to atmospheric INP.

Data management

Project results and data products will be distributed through the internet and public media for the broader community. Project results will be published in journals of the AGU (American Geophysical Union), AMS (American Meteorological Society), EGU (European Geosciences Union) and will be presented on the major international conferences and symposia.

All project data sets will be maintained according to the FAIR (Findability, Accessibility, Interoperability, Reusability) data principles. All raw data (level 0 products) will be stored on different devices and platforms with automatic backup. Preliminary and processed data (level 1 products) are shared with the project partners and associated partners via a jointly used cloud storage server in recognised formats together with readme-files and are available to others upon request.

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data. This project is supported by the German Research Foundation, DFG grants WE 2757/6-1 and HE 5214/10-1.

In all publications based on this expedition, the Grant No. AWI_PS131_04 will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

References

Abbatt J et al. (2019) Overview paper: New insights into aerosol and climate in the Arctic. Atmos. Chem. Phys., 19, 2527–2560.

Ackerman AS et al. (2000) Reduction of tropical cloudiness by soot. Science, 288, 1042-1047.

Bisiaux MM et al. (2011) Stormwater and Fire as Sources of Black Carbon Nanoparticles to Lake Tahoe. Environ. Sci. Technol., 45, 2065-2071.

Bond TC et al. (2013) Bounding the role of black carbon in the climate system: A scientific assessment. J. Geophys. Res., 118, 5380-5552.

Contini D et al. (2010) Deposition velocity of ultrafine particles measured with the eddy-correlation method over the Nansen Ice Sheet (Antarctica). J. Geophys. Res., 115, D16202.

Costa A et al. (2017) Classification of Arctic, midlatitude tropical clouds in the mixed-phase temperature regime. Atmos. Chem. Phys., 17, 12219-12238.

Creamean JM et al. (2018) Marine and terrestrial influences on ice nucleating particles during continuous springtime measurements in an Arctic oilfield location. Atmos. Chem. Phys., 18, 18023–18042.

Ding S et al. (2019) Size–Related Physical Properties of Black Carbon in the Lower Atmosphere over Beijing and Europe. Environ. Sci. Technol., 53, 11112–11121.

Dlugi R (1989) Chemistry and Deposition of Soot Particles in Moist Air and Fog. Aerosol Science and Technology, 10, 93-105.

Gong X et al. (2020a) Characterization of aerosol particles at Cape Verde close to sea and cloud level heights - Part 2: ice nucleating particles in air, cloud and seawater. Atmos. Chem. Phys., 20, 1451-1468.

Gong X et al. (2020b), Characterization of aerosol particles at Cape Verde close to sea and cloud level heights - Part 1: particle number size distribution, cloud condensation nuclei and their origins. Atmos. Chem. Phys., 20, 1431-1449.

Grönlund A et al. (2002) Aerosol dry deposition measured with eddy-covariance technique at Wasa and Aboa, Dronning Maud Land, Antarctica. Ann. Glaciol., 35, 355–361.

Hartmann M et al. (2020) Wintertime airborne measurements of ice nucleating particles in the high Arctic: a hint to a marine, biogenic source for Ice Nucleating Particles. Geophys. Res. Lett., 47, e2020GL087770.

Hartmann M et al. (2021) Terrestrial or marine – indications towards the origin of Ice Nucleating Particles during melt season in the European Arctic up to 83.7°N. Atmos. Chem. Phys., 21, 11613-11636.

Haywood JM, Shine KP (1995) The effect of anthropogenic sulfate and soot aerosol on the clear sky planetary radiation budget. Geophys. Res. Lett., 22, 603-606.

Held A et al. (2011a) On the potential contribution of open lead particle emissions to the central Arctic aerosol concentration. Atmos. Chem. Phys., 11, 3093-3105.

Held A et al. (2011b) Near-surface profiles of aerosol number concentration and temperature over the Arctic Ocean. Atmos. Meas. Tech., 4, 1603-1616.

Jacobson MZ (2012) Investigating cloud absorption effects: Global absorption properties of black carbon, tar balls, and soil dust in clouds and aerosols. J. Geophys. Res., 117, D06205.

Jurado E et al. (2008) Atmospheric deposition of organic and black carbon to the global oceans. Atmos. Environ, 42, 7931-7939.

Maskey S et al. (2017) Cloud Condensation Nuclei Activation of Internally Mixed Black Carbon Particles. Aerosol Air Qual. Res., 17, 867-877.

McCluskey CS et al. (2018a) Observations of Ice Nucleating Particles over Southern Ocean waters. Geophys. Res. Lett., 45, 11989-11997.

McCluskey CS et al. (2018b) Marine and Terrestrial Organic Ice-Nucleating Particles in Pristine Marine to Continentally Influenced Northeast Atlantic Air Masses. J. Geophys. Res., 123, 6196-6212.

Morrison H et al. (2012) Resilience of persistent Arctic mixed-phase clouds. Nat. Geosci., 5, 11-17.

Motos G et al. (2019) Droplet activation behaviour of atmospheric black carbon particles in fog as a function of their size and mixing state. Atmos. Chem. Phys., 19, 2183-2207.

Nilsson ED, Rannik Ü (2001) Turbulent aerosol fluxes over the Arctic Ocean: 1. Dry deposition over sea and pack ice. J. Geophys. Res., 106, 32125–32137.

Ohata S et al. (2013) Evaluation of a Method to Measure Black Carbon Particles Suspended in Rainwater and Snow Samples. Aerosol Science and Technology, 47, 1073-1082.

Quinn PK et al. (2011) The impact of Black Carbon on Arctic Climate. Artic Monitoring and Asessment Programme, AMAP Technical Report No. 4. Arctic Monitoring and Assessment Programme (AMAP), Oslo. 72 pp.

Raatikainen T et al. (2015) Black carbon concentrations and mixing state in the Finnish Arctic. Atmos. Chem. Phys., 15, 10057–10070.

Šantl-Temkiv T et al. (2019) Biogenic sources of Ice Nucleation Particles at the high Arctic site Villum Research Station. Environ. Sci. Technol., 53, 10580-10590.

Saylor RD et al (2019) The particle dry deposition component of total deposition from air quality models: right, wrong or uncertain? Tellus B, 71, 1550324.

Schroder JC et al. (2015) Size-resolved observations of refractory black carbon particles in cloud droplets at a marine boundary layer site. Atmos. Chem. Phys., 15, 1367-1383.

Schwarz JP (2008) Measurement of the mixing state, mass, and optical size of individual black carbon particles in urban and biomass burning emissions. Geophys. Res. Lett., 35, L13810.

Scott WD, Levin Z (1972) Open channels in sea ice (leads) as ion sources. Science, 177, 425-426.

Serreze MC, Barry RG (2011) Processes and impacts of Arctic amplification: A research synthesis. Global and Planetary Change, 77, 85-96.

Si M et al. (2019) Concentrations, composition, and sources of ice-nucleating particles in the Canadian High Arctic during spring 2016. Atmos. Chem. Phys., 19, 3007–3024.

Solomon A et al. (2018) The relative impact of cloud condensation nuclei and ice nucleating particle concentrations on phase partitioning in Arctic mixed-phase stratocumulus clouds. Atmos. Chem. Phys., 18, 17047-17059.

Tobo Y et al. (2019) Glacially sourced dust as a potentially significant source of ice nucleating particles. Nat. Geosci., 12, 253-258.

Torres A et al. (2014) Measuring Organic Carbon and Black Carbon in Rainwater: Evaluation of Methods. Aerosol Science and Technology, 48, 239-250.

Twomey S (1974) Pollution and the planetary albedo. Atmos. Environ., 8, 1251-1256.

Welti A et al. (2020) Ship-based measurements of ice nuclei concentrations over the Arctic, Atlantic, Pacific and Southern Ocean. Atmos. Chem. Phys., 20, 15191-15206.

Wex H et al. (2019) Annual variability of ice nucleating particle concentrations at different Arctic locations. Atmos. Chem. Phys., 19, 5293–5311.

Whitehead JD et al (2012) Particle fluxes and condensational uptake over sea ice during COBRA. J. Geophys. Res., 117, D15202.

Zanatta M et al. (2018) Effects of mixing state on optical and radiative properties of black carbon in the European Arctic. Atmos. Chem. Phys., 18, 14037–14057.

Zanatta M et al. (2021) Technical note: Sea salt interference with black carbon quantification in snow samples using the single particle soot photometer. Atmos. Chem. Phys., 21, 9329–9342.

Zeppenfeld S et al. (2020) A protocol for quantifying mono- and polysaccharides in seawater and related saline matrices by electro-dialysis (ED) – combined with HPAEC-PAD. Ocean Sci., 16, 817–830.

5. PLANKTON ECOLOGY AND BIOGEOCHEMISTRY IN THE CHANGING ARCTIC OCEAN (PEBCAO GROUP)

Katja Metfies[1], Barbara Niehoff[1], Christian Hohe[1], Nadine Knüppel[1], Moritz Zeising[1], Lisa W. von Friesen[2], Johanna Schüttler[3], Ellen Oldenburg[4]
Not on board: Astrid Bracher[1], Eva-Maria Nöthig[1], Ilka Peeken[1], Lasse Riemann[2], Alexandra Gutmann[3]

[1]DE.AWI
[2]DK.KU
[3]DE.MPIC
[4]DE.HHU

Grant No. AWI_PS131_5

Objectives

The Arctic Ocean has gained increasing attention in recent decades due to the drastic decrease in sea ice and increase in temperature, which is approximately twice as fast as the global average. The effects of such changes on the polar plankton ecology and biogeochemical processes (PEBCAO) can only be detected via a well-coordinated approach integrating dedicated process-studies with long-term observations. Here, assessing alterations of environmental drivers, such as sea ice distribution, thickness and melt dynamics on Arctic marine primary production, food web dynamics and nutrient cycling across the sea ice-ocean interface are critical, considering the previously mentioned decline in Arctic sea ice extent. The PEBCAO group began its studies on plankton ecology in the Fram Strait (~79°N) in 1991. Since 2009 it intensified its efforts by accomplishing yearly long-term observations in the framework of the LTER HAUSGARTEN in Fram Strait. The long-term studies were complemented by dedicated process studies in Nansen and Amundsen Basin of the Central Arctic Ocean (CAO) and a participation in the MOSAiC drift experiment. Among the previous study areas of the PEBCAO missions, Fram Strait and the western Nansen Basin represent areas that are scientifically particularly valuable to study linkages between sea ice and ecosystem functionality and services. It is the area of most intense interactions between the warm, nutrient enriched Atlantic Water (AW) and sea ice, hosting the marginal ice zone (MIZ), that is featuring pronounced frontal zones exerting strong controls on the formation of sea ice, the biology, biogeochemistry.

Over the past decade, the regular observations of the PEBCAO-group included a combination of classical bulk measurements of biogeochemical parameters, microscopy, optical methods, satellite observations, and molecular genetic approaches in a holistic approach.By doing so, we have compiled comprehensive information on annual variability in plankton composition, primary production, bacterial activity and zooplankton composition, including key ecosystem processes such as carbon export. Our long term-observations so far, have already revealed important patterns and changes in diversity. For instance, our results clearly indicate that chlorophyll-*a* (chl-*a*) values increase in summer in the eastern but not in the western Fram Strait (Nöthig et al. 2015 & 2020). This is in accordance to the increasing contributions of *Phaeocystis pouchetii* and nanoflagellates to the summer phytoplankton community. The concentration of dissolved organic carbon (DOC) was relatively stable over the last two decades, but we observed a slight decrease in the particulate organic carbon (POC) during the summer months (Engel et al. 2019). This could suggest that the phytoplankton composition affected the POC. We also observed that *Themisto compressa*, an invading amphipod species, increased in abundance (Kraft et al. 2013, Schröter et al. 2019). All this suggests that the ecosystem in Fram Strait is subject to profound changes, likely induced by climate conditions, which warrants further, sustained observation. Considering this, PEBCAO group aims at improving our mechanistic understanding of biogeochemical and microbiological feedback processes in the Arctic Ocean, documenting ongoing and long-term changes in the biotic and abiotic environment and assessing the potential future consequences of these changes. In particular we aim to identify climate-induced changes in the biodiversity of pelagic ecosystems and, concomitantly, in carbon cycling and sequestering.

PEBCAO at the sea-ice Ocean interface and upper water column of the MIZ:

Sea ice is of major importance in the polar oceans since it affects the solar radiation fluxes due to its reflective properties and it is a habitat and feeding ground for various organisms of the polar ecosystem. Changing transport routes and thinning of sea ice (Krumpen et al. 2019) might have major implications on the biodiversity of the sea ice biota, as it has been found that sea ice origin governs the community distribution of e.g. sea ice protists (Hardge et al 2017). A long-term trend towards thinner sea ice and has profound implications for the timing and position of the seasonal ice zone and the anticipated ice-free summers in the future will have major impact on the entire ecosystem and alter biogeochemical cycles in the Arctic.

Primary production constituting the base of the marine food web is expected to increase in the changing Arctic Ocean. It depends, in broad terms, on a balance between stratification and mixing, the former keeping phytoplankton cells within the surface layer, where enough irradiance is available for photosynthesis, and the latter fueling the supply of new nutrients to support production. Here, nutrient availability and flux between sea ice and the upper ocean are key to understand and predict the responses of primary production to rapidly changing conditions. Nitrogen fixation, the biological conversion of N2 to NH3, was up until quite recently not thought to occur in the Arctic marine environment but has now been detected in several habitats of the Arctic Ocean (reviewed in Von Friesen and Riemann, 2020). Knowledge about the prokaryotes responsible for nitrogen fixation (diazotrophs) in this region is however sparse, and no nitrogen fixation rates from sea ice are available.

Meltwater stratification is particularly pronounced in the marginal ice zone (MIZ) of the Arctic Ocean which is defined as an area of the ocean covered with 15-80 % sea ice and characterised by extensive sea ice melt (e.g. Aksenov et al., 2017; Strong and Rigor, 2013). In consequence, the MIZ is a key area of Arctic marine primary production (Gradinger and Baumann, 1991). Overall, there has been an increase in the areal extent of the MIZ reflected by low surface salinity and stratification in the seasonal ice zone of the Arctic Ocean. Observations from recent expeditions suggest, that the area impacted by sea ice melt in Fram Strait might extend south-eastwards. This was particular obvious in summer 2021, when the sea ice edge in June extended to south of 79°N at ~4°E. It is currently unclear whether an increased meltwater concentrations and stratification will lead to increased export of particulate organic carbon or whether the products of primary production will remain at the surface and drive a regenerating system. Arctic regions impacted by melting sea ice support specific plankton community composition (Weiss in prep.; Oldenburg in prep), and may either increase particle export (Lalande et al., 2019, Fadeev et al., 2021) or retain particles at the surface for a while, depending on the physical structure of the respective water parcels at the surface (v. Appen et al., 2021). Retention rates of biomass in the upper water column might change in the future, due to expected changes in plankton communities and trophic networks in consequence to Arctic environmental change. These changes might include that small algae gain importance in mediating element and matter turnover as well as energy fluxes in Arctic pelagic systems. However, currently cryo-pelagic coupling of microalgal communities and the role of sea-ice algae in primary production under the ice, and particularly in the MIZ has to be better understood to estimate consequences of sea ice decline on Arctic primary production and carbon cycles. A combination of measurements of classical parameter (particulate organic carbon, nitrogen, biogenic silica) and molecular biodiversity studies provided first insights into microbial distribution and chl-a biomass in the Arctic Ocean and suggest a high contribution of small microalgae to chl-a biomass in the Central Arctic Ocean (Metfies et al., 2016). Many zooplankton species are affected by changes at the base of the food web as they rely on phytoplankton as food source. Furthermore, zooplankton community composition may shift due to the increasing inflow of warmer Atlantic water into the Fram Strait. Altered zooplankton trophic interactions and community compositions will have consequences for the carbon sequestration and flux.

Comprehensive understanding of the impact of changing environmental conditions on ecosystem functions and functionality requires studying the system on different spatial and temporal scales. This can be accomplished by combining different observation approaches, providing different kinds of information: (i) satellite-based observations can provide geographically large-scale information on changes in ecosystem functions, such as chl-a concentrations over bigger time-scales; (ii) the deployment of sediment traps and automated water samplers for molecular biodiversity studies over extended periods of time in different parts of the Arctic Ocean can provide insight into algal and matter export in different sea ice scenarios over the annual cycle; (iii) underway sampling and towed optical plankton observations can provide high-resolution information on plankton distribution in the upper water column (Weiss et al.; Sprong et al., in prep); (iv) classical CTD sampling and net-tows provide samples for vertical characterization of plankton distribution in the water column.

Arctic marine nitrogen fixation impacted by glacial outflow

From east Greenland, detailed studies of sea ice and adjacent ecosystems are restricted to the subarctic region in the Young Sound at 74°N. Little is known about land fast sea ice biology north of 74°N and preliminary results from the *Polarstern* PS87 cruise indicate very low standing stocks of sea ice algae in this region. The current expedition will allow more detailed biological studies in this under-sampled area. Glacial runoff has further profound impact on the production regime of receiving marine waters. Many Arctic glaciers are currently rapidly retreating, but numerous knowledge gaps remain along the glacier-marine continuum. During this expedition, we aim to assess pelagic nitrogen and carbon fixation along a gradient from the glacial plume through the receiving fjords, targeting contrasting glaciers (marine- and land-terminating) along the east coast of Greenland. This will enable an investigation of the contribution of nitrogen fixation to nitrogen flux and production in glacier-impacted waters. If possible, experimental manipulation to assess limiting factors of nitrogen fixation will be performed.

Assessing selenium concentrations in the Arctic

At the interface between the atmosphere and ocean, sea ice acts as a thin, ephemeris and actively changing environment through which heat, momentum and mass are regulated (Lannuzel et al. 2020). The changes in sea ice also influence the atmospheric boundary layer, by an increase of sensible and latent heat fluxes above open water and thinner ice. Transect from temperate to the ice covered Arctic revealed large change of trace gases occur with e.g. highest concentrations of carbon monoxide and isoprene in the ice covered region (Tran et al. 2013). No studies currently exist about atmospheric selenium in the Arctic.

The selenium cycle, and thus the global distribution of selenium resources, is thought to be driven significantly by marine emissions carried out by phytoplankton. The oceans are sinks for atmospheric selenium and these organisms can volatilize local and oxidized selenium forms by methylation and thus transfer them back from the ocean to the atmosphere. The close connection to the sulphur cycle and already observed high sulphur emissions from polar phytoplankton species suggest a significant influence of the Polar Regions on the global selenium cycle. To date, atmospheric selenium occurrences have been predicted predominantly by model calculation (Feinberg et al., 2020). Actual measurements to confirm current ideas about the selenium cycle are very limited. As a result of ongoing climate change, the global distribution of phytoplankton will be altered due to seawater pH and temperature changes, potentially changing marine Se emissions (Williams and Crutzen, 2013). This could significantly disrupt the global Se circulation. Therefore, data sets are needed as soon as possible to indicate future changes. Thus the current cruise allows to access the role of selenium emissions on a longitudinal transect, which will be further substituted by the measurements of other volatile organic compounds, since the methods is not limited to selenium.

Contributing to the general scientific aims of PEBCAO, the specific objectives on ATWAICE (PS131) are:

1. Characterise plankton distribution and biomass horizontally at the meso-scale with high resolution in the MIZ and adjacent areas.
2. Elucidate cryo-pelagic coupling of microbial (prokaryotic and eukaryotic) communities with respect to small scale meltwater mediated differences in the structuring of the water column.
3. Analyzing the abundance, biodiversity and community structure of sea ice-associated biota and quantifying ecosystem functions and their relationships with biodiversity.
4. Investigating amount and composition of CDOM and their interplay with phytoplankton.
5. Characterisation of the underwater light field and its interplay with optical constituents, such as phytoplankton and CDOM abundance and composition.
6. Measure nitrogen and carbon fixation in different sympagic habitats and characterise present and active diazotrophic communities to understand the role of nitrogen fixation in different types of sea ice.
7. Develop a method allowing biological rate measurements of intact sea ice cores (i.e. not pre-melted).
8. Investigate the magnitude and role of nitrogen fixation in glacial-impacted marine waters of contrasting glaciers and characterise present and active diazotrophic communities.
9. Determine marine selenium and other VOC's emissions from biological activity.

Work at sea

Biogeochemical & biological parameters from rosette samples, the automated filtration system for marine microbes AUTOFIM & deployment of moored sediment traps and automated water samplers

We will sample Arctic seawater with the CTD/rosette sampler at 5 to 6 depths in the upper 200 m of the water column, and using a peristaltic pump system at the ice-ocean interface. At some selected stations in open water, in the marginal ice zone and under closed sea ice cover, the sea water will also be sampled at greater depths. Besides sampling particles in the water column, two sediment traps and automated water samplers (Remote Access Samplers, McLane) will be deployed in an oceanographic mooring to investigate the vertical particle flux in the region northeast of Spitsbergen. Further details can be found in the Chapter 2 (Physical oceanography).

In addition, we will collect particles for molecular characterisation of the microbial communities close to the surface (~ 10 m) with the **auto**mated **fi**ltration system for marine **m**icrobes AUTOFIM (Fig. 5.1: Using AUTOFIM, we will collect seawater samples at regular intervals (~ 1° longitude/latitude on the way to the study area and ~ 2 km in the MIZ) starting as soon as possible after *Polarstern* has left Bremerhaven. AUTOFIM allows filtration of a sampling volume of up to 5 litres. Twelve filters can be automatically taken in a row and stored in a sealed sample archive. Prior to the storage, a preservative can be applied to the filters to prevent degradation of the sample material that will be used for eDNA analyses with special emphasis on eukaryotic microbes.

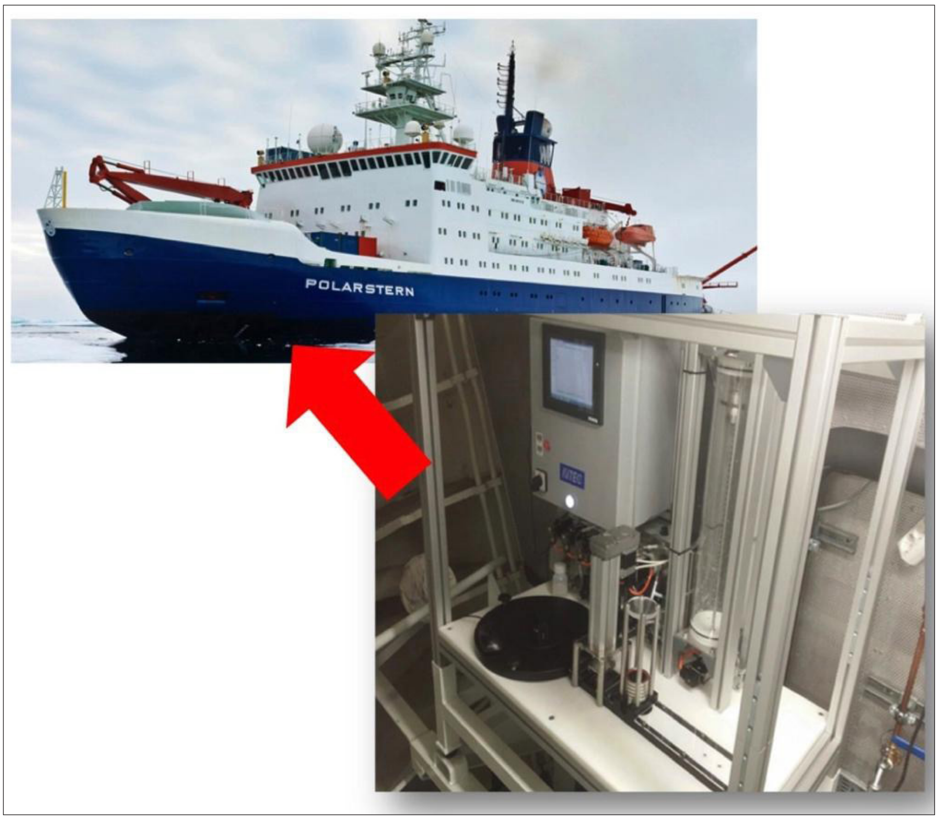


Fig. 5.1: The fully automated filtration module AUTOFIM is installed on Polarstern in the "Bugstrahlruderraum" close to the inflow of the ships-pump system. AUTOFIM is suitable for collecting samples with a maximum volume of 5 Liters. Filtration can be triggered on-demand or after fixed intervals.

All other samples will be partly filtered and preserved or frozen at – 20° C and partly at – 80°C for further analyses. The traps samples will be returned after a year of sampling in 2023 to AWI Bremerhaven. At the home laboratory at AWI, we will determine the following parameters to describe the biogeochemistry, biomass and abundance/biodiversity:

- Chlorophyll *a* concentration (total and fractionated)
- Phytoplankton pigments and major groups (HPLC)
- Dissolved organic carbon (DOC)
- Particulate organic carbon (POC)
- Particulate organic nitrogen (PON)

- Particulate biogenic silica (PbSi)
- Total particulate matter (Seston, at selected stations, depth)
- Phytoplankton abundance
- Molecular based information (Next Generation Sequencing, quantitative PCR) on community structure, diversity and distributional patterns of eukaryotic microbes based on high-resolution underway sampling in the upper water column via the automated sampling system AUTOFIM and depth-resolved sampling at selected sites via CTD-sampling

Zooplankton

We will study the zooplankton biodiversity and biogeography by deploying a multi net in Fram Strait and the Arctic Ocean. These net samples will be immediately preserved in 4 % formalin, buffered with hexamethylentetramin, and later the mesozooplankton composition, biomass, size structure and depth distribution will be determined using the lab-based ZooScan system (Cornils et al., submitted). However, standard multi sampling depths are 1,500 – 1,000 – 500 – 200 – 50 m, and, thus, these nets integrate over several hundred meters. To determine the fine scale vertical distribution of key species, we therefore also use a novel optical system – the zooplankton recorder LOKI (Lightframe On-sight Key species Investigations, Fig. 5.2), which continuously takes pictures of organisms and particles at a frame rate of approx. 20 f sec^{-1} during casts from 1,000 m to the surface.

Fig. 5.2: The LOKI (Lightframe On-sight Key species Investigations) during deployment in Fram Strait. The LOKI is equipped with a 150 µm plankton net that leads to a flow-through chamber with a 6.3 Mpix camera and LED flash lights; images are stored on the under-water computer unit, and will be down-loaded onboard immediately after each cast.

In addition, we will mount a LOKI on the TRIAXUS (see Chapter 5 Physical Oceanography), aiming for a high resolution of the horizontal distribution of key zooplankton species in the upper 300 m of the water column. To account for the faster speed of the TRIAXUS tow, the LOKI has been refined and a pump has been installed to ensure a constant water flow through the chamber to which the camera is attached. This new technique is tested during this cruise for the first time. Onboard, we will therefore download the data immediately after the cast, and adjust the method to the two specific requirements. Linked to each LOKI image, hydrographical parameters will be recorded, i.e. salinity, temperature, oxygen concentration, and fluorescence. This will allow us to exactly identify distribution patterns in relation to environmental conditions. The ice edge which is characterised by strong gradients in abiotic and biotic factors, is especially important for the zooplankton, and our monitoring research in Fram Strait (since 2011) confirms high secondary production in its vicinity. During ATWAICE, we will thus specifically tackle the changes of the zooplankton community in relation to the distance to the ice edge, and combine our data with the high-resolution environmental data as provided by phytoplankton ecologists and physical oceanographers.

Sea ice work and incubations

Sea ice cores will be collected for biological, chemical and biogeochemical analyses during individual ice stations (Fig. 5.3) reached by ship, helicopter or zodiac. We will further sample sack holes, water just below the ice, water from chlorophyll max below the ice and melt pond water if present. The sampling depth under the ice will be based on CTD-profiles conducted prior to the water sampling. We will measure environmental parameters of sea ice such as temperature, snow depth, porosity, freeboard and ice thickness.

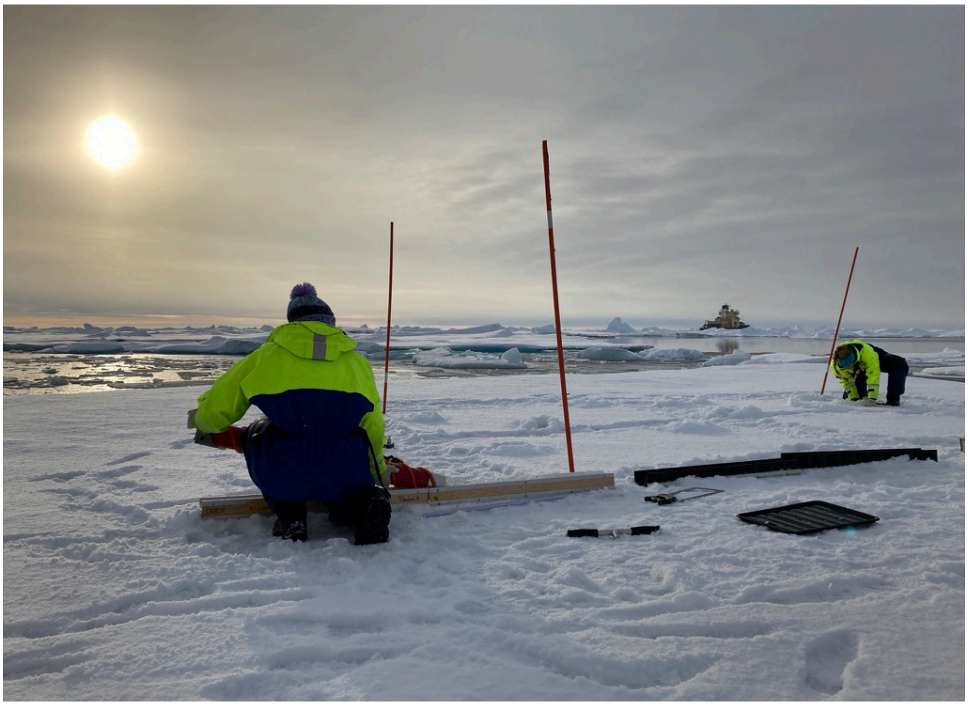


Fig. 5.3. A sea ice coring field (within the orange poles) and ongoing ice thickness measurement and core processing in cradles; photo: Lisa W. von Friesen

The water and ice core samples will be transported back to the ship. We aim to measure the following variables: temperature, salinity, inorganic nutrients, algae biomass and composition (determined by marker pigments), DNA, RNA, cell counts (microscopy) and biogenic silicate. In addition, particulate organic carbon and nitrogen (POC, PON) and its isotopic composition (δ13C and δ15N) will be determined.

Different sea ice types (first-, second-, multi-year and land-fast) are aimed to be sampled and in addition, a methodology for incubation of intact ice core pieces will be developed and tested with the aim of obtaining carbon and nitrogen fixation rates with maximal environmental realism. Incubations for nitrogen and carbon fixation will be started once back on ship and will take place in a light-adjusted on-deck incubator with continuously flowing seawater to simulate *in-situ* conditions (Fig. 5.4). For pelagic samples, water will be collected with the CTD/rosette sampler (two depths in glacial-impacted waters, one depth at sea ice stations – possibly collected with a submersible pump), and the same parameters as above will be analysed. Upon termination of stable isotope incubations, samples for membrane-inlet mass spectrometry (MIMS), elemental-analyser isotope ratio mass spectrometry (EA-IRMS) and nanoscale secondary ion mass spectrometry (nanoSIMS) analysis will be collected. Diazotroph community composition and activity will be investigated based on the marker gene nifH (DNA and RNA samples).Through this study, a broader understanding of sea ice as a potential habitat for nitrogen fixation will be gained.

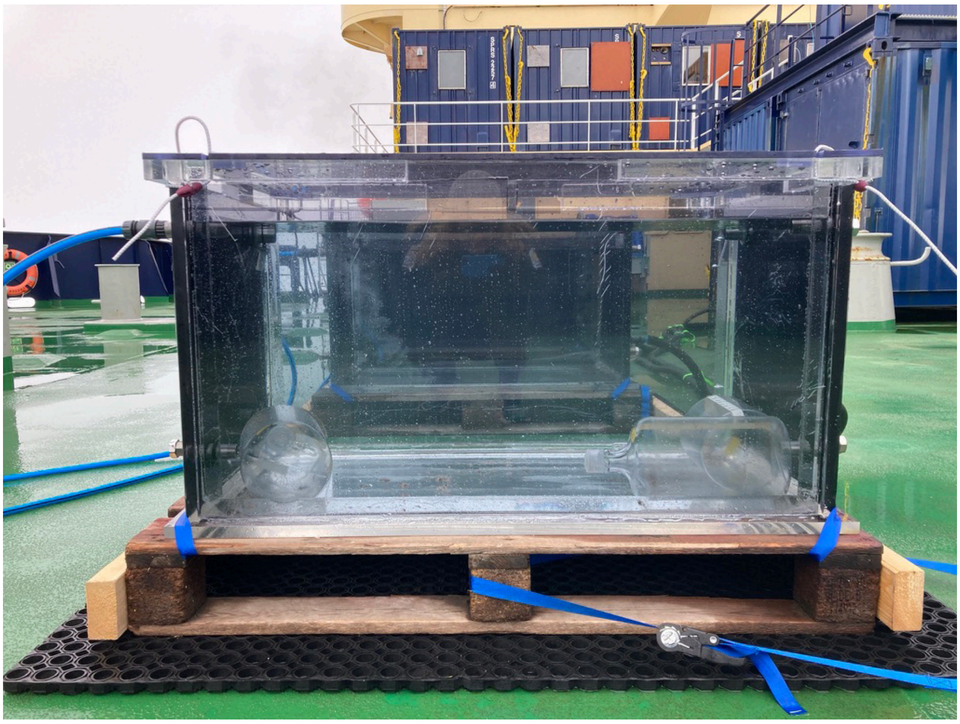


Fig. 5.4: On-deck incubator with continuous flow-through of seawater; photo: Lisa W. von Friesen

Atmospheric measurements

Volatile organic compounds (VOC, such as methylated selenium compounds) can be retained and enriched using adsorption cartridges. A successful proof of concept study has already been conducted to ensure that organic selenium compounds can be measured from phytoplankton cultures by adsorption cartridge measurements. In order to gain a first impression of the actual global distribution of these atmospheric selenium compounds and to obtain a basis dataset for the calculation of fluxes from the Polar Regions, we plan to generate an extensive field measurement dataset during this trip. For regular and low-effort sampling, we use an autosampler (Fig. 5.5) that can sample inserted cartridges gradually at a slow flow rate (100 ml/min). Sampled cartridges are sealed and stored refrigerated at –20° C. To aid interpretation, CO_2 (Li-Cor analyser; Fig. 5.5) will be placed next to the cartridges to detect possible sampling of the ships own emissions.

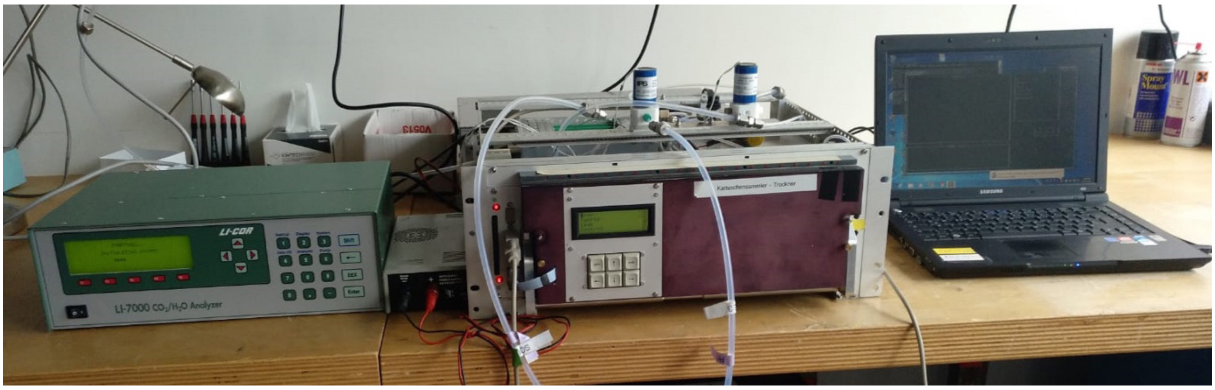


Fig. 5.5: Li-Cor CO_2 analyser and autosampler for cartridges; photo taken by Johanna Schüttler

Additionally, canisters will be filled with air to allow comparison of what is collected on the adsorption tubes with direct analysis of air. If possible, frozen water samples will be taken to analyse the inorganic selenium concentrations in the sea water and compare them to the volatile organic selenium in the atmospheric samples.

Continuous optical measurements

The contribution of the Phytooptics group is the acquisition of high resolved information on the amount and composition of phytoplankton and its pigments, dissolved organic matter and particles along the cruise transect. Via the complementation to satellite and previous field data acquisition, these data enable the analysis of long-term trends of these parameters in the East Greenland region. At this expedition, continuous measurements with optical sensors will be taken at the surface water and within the euphotic zone of the water column at transects towed with the TOPAWI platform, but also at discrete stations with the light profiler. With that, as much as possible collocated data to ocean colour sensors OLCI data (launched in February 2016 and April 2018, respectively, on Sentinel-3A and -3B) shall be acquired for validation (The Phytooptics groups is within the Sentinel-3 Validation Team). In addition to that, these *in-situ* data are important for the validation of the group's own satellite products on phytoplankton composition and its distribution (EOF-PFT Xi et al. 2020, 2021; PhytoDOAS Bracher et al. 2009, Sadeghi et al. 2012) and light penetration depth (Oelker et al. 2022). The continuous surface and profile biooptical data are regularly calibrated with measurements at discrete water samples determining the phytoplankton pigment composition using HPLC method and the optical properties using spectrophotometric instrumentation.

Active and passive bio-optical measurements for the survey of the underwater light field, specific light attenuation, particle and phytoplankton composition and distribution shall be performed continuously on the surface water but also in the profile during topAWI operation and daily noon-time CTD stations:

1. Continuous measurements of inherent optical properties (IOPs) with a hyperspectral spectrophotometer: For the continuous underway surface sampling an *in-situ*–spectrophotometer (ACS; Wetlabs) will be operated in flow-through mode to obtain total and particulate matter attenuation and absorption of surface water. The instrument is mounted to a seawater supply taking surface ocean water. A flow-control with a time-programmed filter is mounted to the ACS to allow alternating measurements of the total and the CDOM inherent optical properties of the sea water. Flow-control and debubbler-system ensure water flow through the instrument with no air bubbles.

2. A second ACS instrument is mounted on a steel frame together with a depth sensors and a set of hyperspectral radiometers (Ramses sensors from TRIOS) and operated

during CTD stations around noon time daily. measures the inherent optical properties (IOPs: total attenuation, scattering and absorption) in the water profile.The frame is lowered down to maximal 120 m with a continuous speed of 0.1 m/s or during daylight with additionally stops at 2, 4, 6, 8, 10, 12.5, 15, 20, 25 and 30 m to allow a better collection of radiometric data (see later). The Apparent Optical Properties of water (AOPs) (surface reflectance and light attenuation through the water column) will be estimated based on downwelling and upwelling irradiance measurements in the surface water profile (down to the 0.1 % light depth) from the radiometers calibrated for the incident sunlight with measurements of a radiometer on deck.

3. Discrete measurements of IOPs (absorption) at water samples are performed 1) for samples from the underway surface sampling (as for the ACS flow-through system at from the ship's sea water pump) at an interval of 3 hours, 2) for samples from the CTD station water sampling at 6 depths within the top 100 m. Water samples for CDOM absorption analysis are filtered through 0.2 µm filters and analysed onboard with a 2.5 m-path length liquid waveguide capillary cell system (LWCC, WPI) following Levering et al. 2017. Particulate and phytoplankton absorption coefficients are determined with the quantitative filter techniques using sample filtered onto glass-fiber filters QFT-ICAM and measuring them in a portable QFT integrating cavity setup Röttgers et al. 2016).

4. Samples for determination of phytoplankton pigment concentrations and composition are taken at a 3-hourly interval from the underway-sampling system, and from 6 depths (max. 100 m) at CTD-stations. These water samples are filtered on board immediately after sampling and the filters are thermally shocked in liquid nitrogen. Samples are stored at –80° C until the ship is back in Bremerhaven and then will be analysed within the next three months by High Performance Liquid Chromatography Technique (HPLC) at AWI following Taylor et al. (2011) adapted to our new instrumentation as described in Alvarez et al. (2022).

5. The acquisition of optical data (hyperspectral AOPs from three RAMSES sensors, hyperspectral IOPs from a third ACS instrument, Chlorophyll and CDOM fluorescence and backscatter at 550 nm from a wetlabs triplet sensor, and overall visible light from a PAR sensor) during the TOPAWI casts is supported by helping in the control of the output data, calibration of the instruments and later analysis of the data. The measurements of the ACS run continuously at surface (see 1.) and in the water column (see 2.) during stations will be intercompared to the ACS run on the topAWI system to ensure quality control for the topAWI-ACs system. In addition, the discrete measurements of water samples (see 3. and 4.) will be used to calibrate the above mentioned topAWI sensor data.

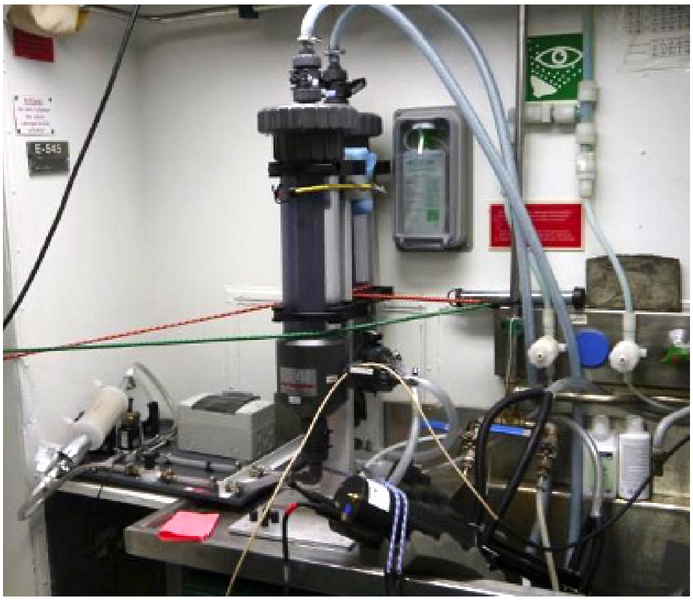


Fig. 5.6: Left: Underwater light field measurements (during FRAM expedition PS99) with TRIOS RAMSES radiometers detecting the hyperspectral up- and downwelling radiation and WETLABS AC-s (including data logger and battery) measuring extinction and absorption within the surface water profile; (in addition, on the right also a SUNA nitrate sensor is mounted on the frame); right: Continuous measurements of the extinction and absorption of light in Arctic surface waters using a WETLABS AC-s mounted to the Polarstern surface seawater pump system. From those measurements directly, the absorption and scattering of particles and CDOM is determined for the whole spectrum in the visible resolved with about 3 nm resolution. This data then can be decomposed various specific algorithms to determine the particle size distribution and the various phytoplankton pigment composition.

Preliminary (expected) results

The continuous measured optical data are used via using semi-analytical techniques to determine the spectrally resolved underwater light attenuation and the concentration of optical constituents, such as chl-a concentration, CDOM absorption and particle backscattering, but also to validate satellite ocean colour retrievals following formerly established procedures for FRAM cruises PS93.2, PS99 and PS107 (see Bracher et al., 2020, Liu et al., 2018, Liu et al., 2019).

Results from sea ice and atmospheric studies are expected to provide a better understanding of i) the variability and biodiversity of sea ice-associated biomass with respect to sea ice characteristics and nutrient availability, ii) the role of sea-ice biota for cryo-pelagic, cryo-benthic coupling under different melt scenarios in the MIZ, iii) the magnitude and role of nitrogen fixation in sea ice habitats, iv) the impact of glacial melt on biological carbon and nitrogen fixation and v) the role of marine Selenium emissions and possible biological sources.

Data management

During our cruises, we sample a large variety of interrelated parameters. Many of the samples (i.e. pigment analyses, particulate matter in the water column, optical measurements, etc.) will be analysed at AWI within approximately one year after the cruise. We plan that the full data set will be available at latest about two years after the cruise. Samples taken for microscopical and molecular analyses, which cannot be analysed within two years after the cruise, will be stored at the AWI for at least ten years and available upon request to other scientists. Data will be made available to the public via the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de).

Molecular work regarding diazotrophs will be performed at the University of Copenhagen. Molecular data (DNA and RNA data) will be archived, published and disseminated within one of the repositories of the International Nucleotide Sequence Data Collaborations (INSDC, www.insdc.org) comprising of EMBL-EBI/ENA, Genbank and DDBJ).

Any other data, such as MIMS, EA-IRMS, nanoSIMS and dual DNA/RNA samples, that will be analysed by the University of Copenhagen, will be submitted to an appropriate long-term archive that provides unique and stable Identifiers for the datasets and allows open online access to the data. All atmospheric samples are destroyed once they are analysed. For atmospheric analysis, the cartridges are desorbed and the air in the canisters measured in the laboratory (MPI for Chemistry in Mainz). ACs data are foreseen to be uploaded to the FRAM data portal as raw data immediately after the cruise and as calibrated data set after carefully executing quality controls and calibrations with discrete water sample measurements. Image material and associated metadata will be uploaded to the planktonnet database (https://planktonnet.awi.de) and these data sets will be integrated into PANGAEA. All image material in planktonnet will be publicly available. Uploads will be made incrementally as phytoplankton analyses progress.

The scientific programme of the PEBCAO-group of this expedition was supported by the Helmholtz Research Programme “Changing Earth – Sustaining our Future” Topic 6, Suptopics 6.1, 6.2 and 6.3.

In all publications based on this expedition, the Grant No. AWI_PS131_05 will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN operated by the Alfred-Wegener-Institute. Journal of lage-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

References

Aksenov Y, Popova EE, Yool A, Nurser AJG, Williams TD, Bertino L, Bergh J (2017) On the future navigability of Arctic sea routes: High-resolution projections of the Arctic Ocean and sea ice, Mar. Pol., 75, 300–317, https://doi.org/10.1016/j.marpol.2015.12.027

Álvarez E, Losa S, Bracher A, Thoms S, Völker C (submitted) Impact of non-photosynthetic pigments content in the global variability of phytoplankton absorption coefficients. JAMS.

Bracher A, Vountas M, Dinter T, Burrows JP, Röttgers R, Peeken I (2009) Quantitative observation of cyanobacteria and diatoms from space using PhytoDOAS on SCIAMACHY data. Biogeosciences 6: 751-764, https://doi.org/10.3389/fmars.2020.00235

Bracher A, Vountas M, Dinter T, Burrows JP, Röttgers R, Peeken I (2009) Quantitative observation of cyanobacteria and diatoms from space using PhytoDOAS on SCIAMACHY data. Biogeosciences 6: 751-764

Bracher A, Xi H, Dinter T, Mangin A, Strass VH, von Appen W-J, Wiegmann S (2020) High resolution water column phytoplankton composition across the Atlantic Ocean from ship-towed vertical undulating radiometry. Frontiers in Marine Science 7: s235

Engel A, Bracher A, Dinter T, Endres S, Grosse J, Metfies K, Peeken I, Piontek J, Salter I and Nöthig E-M (2019) Inter-Annual Variability of Organic Carbon Concentration in the Eastern Fram Strait During Summer (2009–2017). Front. Mar. Sci. 6:187, https://doi.org/10.3389/fmars.2019.00187

Fadeev E, Rogge A, Ramondenc S, Nöthig EM, Wekerle C, Bienhold C, Salter I, Waite A, Hehemann L, Boetius A and Iversen M (2021) Sea ice presence is linked to higher carbon export and vertical microbial connectivity in the Eurasian Arctic Ocean, Communications Biology, 4 (1255), https://doi.org/10.1038/s42003-021-02776-w

Feinberg A, Maliki M, Stenke A, Sudret B, Peter T, Winkel LHE (2020) Mapping the drivers of uncertainty in atmospheric selenium deposition with global sensitivity analysis. Atmos. Chem. Phys. 20: 1363-1390, https://doi.org/10.5194/acp-20-1363-2020

Hardge K, Peeken I, Neuhaus S, Krumpen T, Stoeck T, Metfies K (2017) Sea ice origin and sea ice retreat as possible drivers of variability in Arctic marine protist composition. Marine Ecology Progress Series 571: 43-57, https://doi.pangaea.de/10.1594/PANGAEA.878244

Gradinger RR, Baumann MEM (1991) Distribution of phytoplankton communities in relation to the large-scale hydrographical regime in the Fram Strait. Mar. Biol. 111, 311–321, https://doi.org/10.1007/BF01319714

Kraft A, Nöthig EM, Bauerfeind E, Wildish DJ, Pohle GW, Bathmann UV, Beszczynska-Möller A, Klages M. (2013) First evidence of reproductive success in a southern invader indicates possible community shifts among Arctic zooplankton. Marine Ecology-Progress Series, 493 , pp. 291-296, https://hdl.handle.net/10013/epic.42685

Krumpen T, Belter HJ, Boetius A, Damm E, Haas C, Hendricks S, Nicolaus M. Nöthig EM, Paul S, Peeken I, Ricker R, Stein R. (2019) Arctic warming interrupts the Transpolar Drift and affects long-range transport of sea ice and ice-rafted matter. Sci Rep 9, 5459 (2019), https://doi.org/10.1038/s41598-019-41456-y

Lalande C, Nöthig EM and Fortier L (2019) Algal Export in the Arctic Ocean in Times of Global Warming Geophysical Research Letters 46, 5959–5967, https://doi.org/10.1029/2019GL083167

Lannuzel D, Tedesco L, Van Leeuwe M, Campbell K, Flores H, Delille B, Miller L, Stefels J, Assmy P, Bowman J, Brown K, Castellani G, Chierici M, Crabeck O, Damm E, Else B, Fransson A, Fripiat F, Geilfus NX, Jacques, Jones H. Kaartokallio M, Kotovitch K, Meiners S, Moreau, Nomura D, Peeken I, Rintala JM, Steiner N, Tison JL, Vancoppenolle M, Van Der Linden F, Vichi M, Wongpan P (2020). The future of Arctic sea-ice biogeochemistry and ice-associated ecosystems. Nature Climate Change, 10 (11), pp. 983-992, https://doi.org/10.1038/s41558-020-00940-4

Lefering I, Röttgers R, Utschig, McKee D (2017): Uncertainty budgets for liquid waveguide CDOM absorption measurements. Applied Optics, 56(22), 6357, https://doi.org/10.1364/AO.56.006357

Liu Y, Roettgers R, Ramírez-Pérez M, Dinter T, Steinmetz F, Noethig EM, Hellmann S, Wiegmann S, Bracher A (2018) Underway spectrophotometry in the Fram Strait (European Arctic Ocean): a highly resolved chlorophyll a data source for complementing satellite ocean color. Optics Express 26(14): A678-A698; doi.org/10.1364/OE.26.00A678

Liu Y, Boss E, Chase AP, Xi H, Zhang X, Röttgers R, Pan Y, Bracher A (2019) Retrieval of phytoplankton pigments from underway spectrophotometry in the Fram Strait. Remote Sensing 11, 318; https://www.mdpi.com/2072-4292/11/3/318

Metfies K, von Appen WJ, Kilias E, Nicolaus A, Nöthig EM (2016) Biogeography and photosynthetic biomass of Arctic marine pico-eukaryotes during summer of the record sea ice minimum 2012. PLoS ONE 11, https://doi.org/10.1371/journal.pone.0148512

Oelker J, Losa SN, Richter A, Bracher A (2020) TROPOMI-retrieved underwater light attenuation in three spectral regions in the ultraviolet to blue. Frontiers in Marine Science 9. 787992. https://doi.org/10.3389/fmars.2022.787992

Nöthig EM, Bracher A, Engel A, Metfies K, Niehoff B, Peeken I, et al. (2015). Summertime plankton ecology in Fram Strait - a compilation of long- and short-term observations. Polar Res. 34:23349, http://dx.doi.org/10.3402/polar.v34.23349

Nöthig E-M, Ramondenc S, Haas A, Hehemann L, Walter A, Bracher A, Lalande C, Metfies K, Peeken I, Bauerfeind E and Boetius A (2020) Summertime Chlorophyll a and Particulate Organic Carbon Standing Stocks in Surface Waters of the Fram Strait and the Arctic Ocean (1991–2015). Front. Mar. Sci. 7:350. https://doi.org/10.3389/fmars.2020.00350

Röttgers R, Doxaran D, Dupouy C (2016) Quantitative filter technique measurements of spectral light absorption by aquatic particles using a portable integrating cavity absorption meter (QFT-ICAM). Opt. Express, 24, A1–A20, https://doi.org/10.1364/OE.24.0000A1

Sadeghi A, Dinter T, Vountas M, Taylor B, Peeken I, Altenburg Soppa M, Bracher A (2012) Improvements to the PhytoDOAS method for identification of coccolithophores using hyper-spectral satellite data. Ocean Sciences 8: 1055-1070, https://doi.org/10.5194/os-8-1055-2012

Schröter F, Havermans C, Kraft A, Knüppel N, Beszczynska-Möller A, Bauerfeind E and Nöthig E-M (2019) Pelagic Amphipods in the Eastern Fram Strait With Continuing Presence of Themisto compressa Based on Sediment Trap Time Series. Front. Mar. Sci. 6:311. https://doi.org/10.3389/fmars.2019.00311

Strong C, Rigor IG (2013) Arctic marginal ice zone trending wider in summer and narrower in winter, Geophys. Res. Lett., 40, 4864–4868, https://doi.org/10.1002/grl.50928

Taylor BB, Torrecilla E, Bernhardt A, Taylor MH, Peeken I, Röttgers R, Piera J, Bracher A (2011) Bio-optical provinces in the eastern Atlantic Ocean. Biogeosciences 8: 3609-3629. https://doi.org/10.5194/bg-8-3609-2011

Tran S, Bonsang B, Gros V, Peeken I, Sarda-Esteve R, Bernhardt A, and Belviso L. (2013). A survey of carbon monoxide and non-methane hydrocarbons in the Arctic Ocean during summer 2010. Biogeosciences 10: 1909-1935, https://doi.org/10.5194/bg-10-1909-2013

von Appen WJ, Waite AM, Bergmann M, Bienhold C, Boebel O, Bracher A, Cisewski B, Hagemann J, Hoppema M, Iversen MH, Konrad C, Krumpen T, Lochthofen N, Metfies K, Niehoff B, Nöthig EM, Purser A, Salter I, Schaber M, Scholz D, Soltwedel T, Torres-Valdes S, Wekerle C, Wenzhöfer F, Wietz M, Boetius A (2021) Sea-ice derived meltwater stratification slows the biological carbon pump: results from continuous observation, Nature Communications, 12 (1), p. 7309, https://doi.org/10.1038/s41467-021-26943-z

Von Friesen LW, and Riemann L. (2020). Nitrogen Fixation in a Changing Arctic Ocean: An Overlooked Source of Nitrogen? Front Microbiol 11, https://doi.org/10.3389/fmicb.2020.596426

Williams J, and Crutzen PJ. (2013). Perspectives on our planet in the Anthropocene. Environmental Chemistry 10: 269-280, https://doi.org/10.1071/EN13061

Xi H, Losa SN, Mangin A, Garnesson P, Bretagnon M, Demaria J, Soppa MA, d'Andon OHF, Bracher A (2021) Global chlorophyll a concentrations of phytoplankton functional types with detailed uncertainty assessment using multi-sensor ocean color and sea surface temperature satellite products. Journal Geoph. Res.-Oceans 126: e2020JC017127, https://doi.org/10.1029/2020JC017127

Xi H, Losa S, Mangin A, Soppa MA, Garnesson P, Demaria J, Liu Y, Fanton d'Andon O, Bracher A (2020) Global retrieval of phytoplankton functional types based on empirical orthogonal functions using CMEMS GlobColour merged products and further extension to OLCI data. Remote Sensing of Environment 240: 111704. https://doi.org/10.1016/j.rse.2020.111704

6. PELAGIC BIOGEOCHEMISTRY: NUTRIENTS AND NET COMMUNITY PRODUCTION

Sinhué Torres-Valdés[1], Klara Köhler[1], Annika Morische[2], Linda Rehder[1]
Not on board:
Daniel Scholz[1], Sebastian Rokitta[1]

[1]DE.AWI
[2]DE.UNI-Oldenburg-ICBM

Grant-No. AWI_PS131_06

Outline

Productivity in the Arctic Ocean and thus the export of carbon to depth (the biological carbon pump) are sustained by the availability of nutrients in the sunlit layer (Tremblay et al. 2015). Nutrients are supplied via rivers and coastal erosion around the Arctic coast lines (Holmes et al., 2011; Terhaar et al., 2021), and by water mass exchange from the Pacific and Atlantic Oceans through Arctic Ocean gateways (Torres-Valdés et al. 2013, 2016). Rivers and coastal erosion supply nutrients directly to the surface layers on coastal seas, where these become readily available (Terhaar et al., 2021). Oceanic nutrient transport sustains productivity either directly over inflow shallow shelves, or via physical processes (e.g., vertical mixing, eddies) when water masses are subducted (Tremblay et al. 2015). The processes involved in Arctic Ocean dynamics have been affected by climate change (e.g., sea ice extent reduction, increased river loads) and it is still unclear how this, in turn, affects nutrient availability and ultimately, primary productivity. Therefore, understanding the mechanisms of nutrient delivery to the ocean sunlit layers, quantifying nutrient supply and assessing the net primary productivity are of relevance to assess potential effects of climate change on ecosystem functioning and the biological carbon pump.

Objectives

Fram Strait is one of the main Arctic Ocean gateways, through which water masses and associated physical and biogeochemical properties are exchanged with the Nordic Seas and North Atlantic. Atlantic Water (AW) flows north within the West Spitsbergen Current and interacts with surrounding waters, thereby redistributing biogeochemical properties. During the ATWAICE (PS131) expedition, our observation programme has specific goals. One is to generate data to address the scientific aims put forward as part of the expedition project (Objective 1, Question 1 and Objective 2, Question 7 of the ATWAICE proposal). These regard the study of advection of nutrients associated with Atlantic Water, eddies and fronts as well as nutrient fluxes toward the sea ice, and the effect of these processes on Arctic Ocean productivity. A second, and linked goal, is to continue our observations within the framework of the Frontiers in Arctic Marine Monitoring (FRAM) Programme. This aims to study temporal variability of nutrient content associated with the WSC and the EGC, and their relevance to the wider Arctic Ocean nutrient budget. Therefore, measurements will target in areas where water masses of interest flow. In addition to the measurement of nutrients and dissolved oxygen through the water column from CTD/Rosette casts, we aim to deploy Biogeochemical Packages (Remote access samplers, plus sensors) at selected locations in Fram Strait and ATWAICE.

These deployments will be done in collaboration with the Microbial Observatory (Katja Metfies, Christina Bienhold, Anja Nicolaus and Mathias Wietz) and physical Oceanography (Wilken von-Appen, Mario Hoppmann, Matthias Monsees, Torsten Kanzow) and Deep Seas (Normen Lochtofen) groups. The biogeochemical packages are intended to generate high temporal resolution measurement of biogeochemical, microbial and physical variables over a one-year cycle. Quoting our long term goals: "Under ongoing and predicted climate change, identifying and quantifying sinks and sources of nutrients and carbon becomes relevant to: *i)* generate baseline measurements against which future change can be evaluated, *ii)* assess the impact of climate change on biogeochemical processes (e.g., primary production, organic carbon export, remineralisation), *iii)* understand the complex interaction between biogeochemical and physical processes, and how such interactions affect the transport of nutrients downstream and the capacity of the AO to function as a sink of atmospheric CO_2, and to *iv)* determine whether long-term trends occur and what is their origin."

To better understand the magnitude as well as the regionality and seasonality of biogeochemical activity, we will assess concentrations of dissolved O_2 and Ar using membrane-inlet mass spectrometry (MIMS, Fig. 6.1) to determine net community production of transected water masses (Craig and Hayward 1987). Data will be combined with hydrological data (water mass identification), chemical data (nutrient fluxes, CO_2 concentrations), biological data (phytoplankton abundance, chlorophyll abundance), and meteorological data (wind speed) to derive estimates of net community production (Kaiser et al. 2005; Ulfsbo et al. 2014).

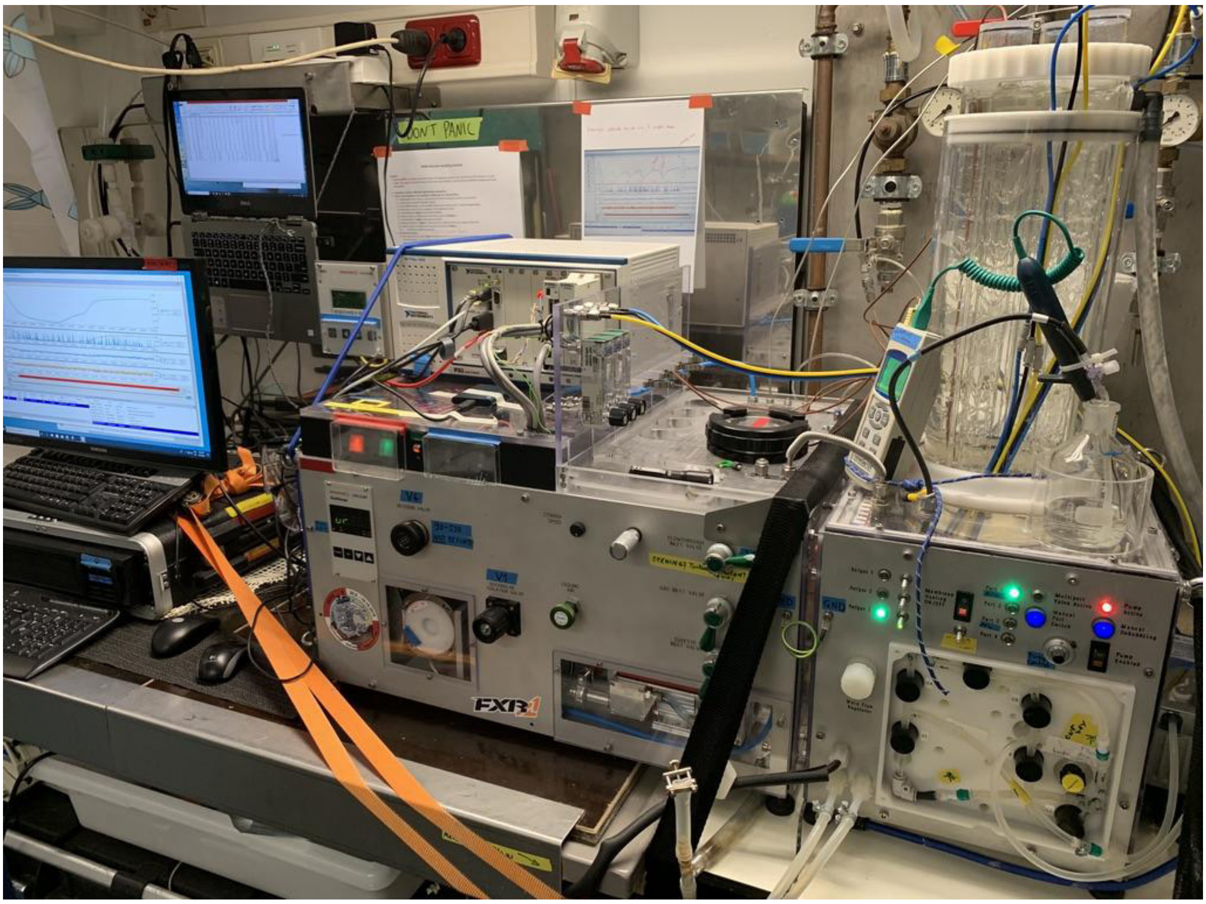


Fig. 6.1: The ship-going MIMS system during the MOSAiC driftWork at sea

During PS131:

1. We will collect water samples from CTD-Rosette casts of dissolved nutrients and dissolved oxygen for the analysis onboard.

2. Starting on PS114 (2018), and continuing on PS121 and PS126, we have deployed (and eventually recovered) a set four package sensors at/from selected locations targeting sub-surface and core waters of the East Greenland Current and West Spitsbergen Current (moorings EGC, F4S and/or F4W-1). Each package consists of a RAS (remote access sampler) with a SUNA nitrate, pH, pCO2, CTD-O2, PAR and Eco-triplet sensors attached. PAR and Eco-triplet are included in surface deployments only. Thus during ATWAICE, we will recover biogeochemical packages deployed during PS126. We will also deploy a further four sets of biogeochemical packages. However, this time we will deploy them only in surface waters; two in Fram Strait (WSC and EGC) and two as part of the ATWICE moorings (under ice and in open waters within the 'IMO' section of the work plan). RAS and sensors will be programmed to take samples and measurements for 1 year.

3. This MIMS work is conducted continuously, i.e., starting after the ship´s departure from, and ending before its arrival in the port of Bremerhaven. No dedicated station or transect time is required during the cruise programme.

Preliminary (expected) results

Provided the instrumentation works onboard, we aim to have water column nutrient and oxygen data by the end of the expedition. Also, provided deployed RAS and sensors functioned as programmed, recovering our biogeochemical packages would yield a third year of observations of biogeochemically relevant variables from the West Spitsbergen and East Greenland Current. Sensor derived data will be processed and calibrated within 6 months after the end of the expedition.

With the MIMS, we will record a high-resolution dataset of O_2: Ar ratios in surface water. We will combine it with the output from the ship's thermosalinograph to derive aequeous O_2 concentrations (Fig. 6.2). Then we will be able to estimate the biological productivity (Kaiser et al. 2005; Ulfsbo et al. 2014). We expect that sea-ice coverage, light regimes, and nutrient fluxes strongly modulate patterns of net community production and the subsequent biogeochemical functioning of the ecosystem in terms of food web input, particle flux and carbon sequestration. We will correlate our obtained data with additional assessments of the mentioned parameters and attempt to quantify the contributions of such abiotic factors.

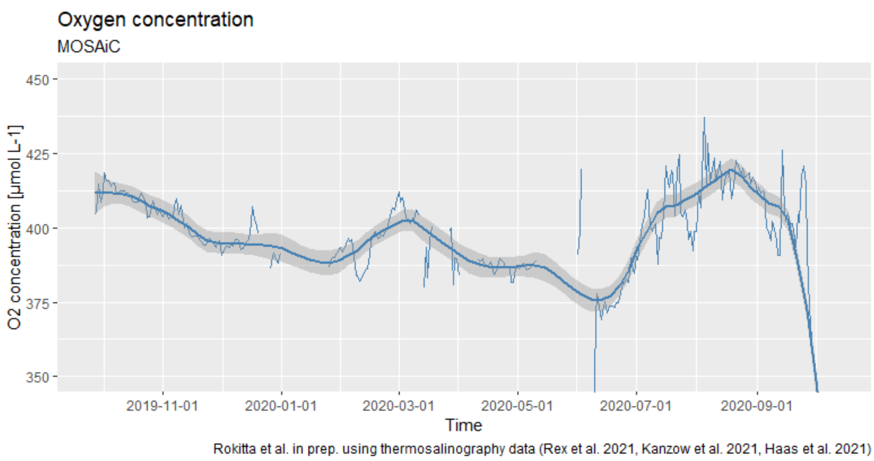


Fig. 6.2: Oxygen concentrations throughout the MOSAiC drift as an example of the anticipated underway data, using data from: Haas et al. (2021); Kanzow et al. (2021); Rex et al. (2021a, b, c)

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

This expedition was supported by the Helmholtz Research Programme "Changing Earth – Sustaining our Future" Topic 6, Subtopic 6.2 and 6.3, Topic 2, Subtopic 2.1.

In all publications based on this expedition, the Grant No. AWI_PS131_06 will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

References

Craig H, Hayward T (1987) Oxygen Supersaturation in the Ocean: Biological Versus Physical Contributions. Science 235:199–202. https://doi.org/10.1126/science.235.4785.199

Haas C, Hoppmann M, Tippenhauer S, Rohardt G (2021) Continuous thermosalinograph oceanography along RV POLARSTERN cruise track PS122/2. https://doi:10.1594/PANGAEA.930024

Holmes RM, McClelland JW, Peterson BJ, et al (2011) Seasonal and Annual Fluxes of Nutrients and Organic Matter from Large Rivers to the Arctic Ocean and Surrounding Seas. Estuaries and Coasts 35:369–382. https://doi.org/10.1007/s12237-011-9386-6

Kaiser J, Reuer MK, Barnett B, Bender ML (2005) Marine productivity estimates from continuous O2/Ar ratio measurements by membrane inlet mass spectrometry. Geophys Res Lett 32:n/a-n/a. https://doi.org/10.1029/2005gl023459

Kanzow T, Hoppmann M, Tippenhauer S, Rohardt G (2021) Continuous thermosalinograph oceanography along RV POLARSTERN cruise track PS122/3. https://doi:10.1594/PANGAEA.930026

Rex M, Hoppmann M, Tippenhauer S, Rohardt G (2021a) Continuous thermosalinograph oceanography along RV POLARSTERN cruise track PS122/1. https://doi:10.1594/PANGAEA.930022

Rex M, Hoppmann M, Tippenhauer S, Rohardt G (2021b) Continuous thermosalinograph oceanography along RV POLARSTERN cruise track PS122/4. https://doi:10.1594/PANGAEA.930027

Rex M, Hoppmann M, Tippenhauer S, Rohardt G (2021c) Continuous thermosalinograph oceanography along RV POLARSTERN cruise track PS122/5. https://doi:10.1594/PANGAEA.930028

Terhaar J, Lauerwald R, Regnier P, et al (2021) Around one third of current Arctic Ocean primary production sustained by rivers and coastal erosion. Nature Communications 12(169): https://doi.org/10.1038/s41467-020-20470-z

Torres-Valdés S, Tsubouchi T, Bacon S, et al (2013) Export of nutrients from the Arctic Ocean. Journal of Geophysical Research 118:1625–1644. https://doi.org/10.1002/jgrc.20063

Torres-Valdés S, Tsubouchi T, Davey E, et al (2016) Relevance of dissolved organic nutrients for the Arctic Ocean nutrient budget. Geophysical Research Letters 43:6418–6226. https://doi.org/10.1002/2016gl069245

Tremblay J-E, Anderson LG, Matrai P, et al (2015) Global and regional drivers of nutrient supply, primary production and CO2 drawdown in the changing Arctic Ocean. Progress In Oceanography 139:171–196. https://doi.org/10.1016/j.pocean.2015.08.009

Ulfsbo A, Cassar N, Korhonen M, et al (2014) Late summer net community production in the central Arctic Ocean using multiple approaches. Global Biogeochemical Cycles 28:1129–1148. https://doi.org/10.1002/2014gb004833

7. GEOPHYSICAL AND OCEANOGRAPHIC EXPLORATION OF AURORA VENT FIELD

Vera Schlindwein[1,2], Henning Kirk[1]
Not on board: Maren Walter[2]

[1]DE.AWI
[2]DE.UNI-Bremen

Grant-No. AWI_PS131_03

Objectives

Polarstern cruise PS137, ALOIS, in 2023 is devoted to a detailed exploration of the geological setting of Aurora vent field at western Gakkel Ridge, the provenance of its hydrothermal fluids and the biota living around the so far only known hydrothermal vent location in the Arctic Ocean. In particular, it is unknown from where the vent mines heat to drive vigorous circulation. Gakkel Ridge belongs to the melt-starved slowest spreading ridges on Earth but exhibits surprisingly active hydrothermalism (Edmonds et al. 2003). Aurora vent field is located on a basalt mound, but the composition of the vent fluids indicates a circulation through mantle rocks. These must therefore either be situated at shallow levels below the basaltic crust or circulation must be deep reaching.

In order to investigate the hydrothermal circulation system, we will record microseismic activity around the vent location for the duration of one year and in parallel monitor the physical properties of its hydrothermal plume. Seismic activity may change circulation paths of the hydrothermal system and hence affect the output of the vent. Furthermore, seismic tremor has proved a suitable tool to study subsurface fluid flow (Meier and Schlindwein 2018). Microearthquakes around the vent will also be used as source of seismic rays for a three-dimensional seismic tomography of the subsurface structure of Aurora vent field. Cruise PS137 will follow up with active seismic surveying of the crust-mantle structure and acquisition of potential field data to complete the geophysical exploration of the vent setting.

Work at sea

We will deploy a network of 8 ocean bottom seismometers in an area of about 20 km x 20 km around Aurora vent field. The ocean bottom seismometers have been modified for recovery in dense sea ice. Following a proto-type test in 2018/19, this will be the first routine survey with the newly designed recovery module attached to the instrument. It consists of a Posidonia transponder that is firmly attached to the OBS during the recording time but will unwind about 200 m of rope upon recovery to hang down freely from the OBS. This is necessary to precisely locate the instruments when they get stuck beneath ice floes during recovery. The instruments will be deployed in free-fall mode and their way to the sea-floor will be tracked by Posidonia such that the exact position on the seafloor is known. The OBS further carry independent temperature sensors that register any potential changes in water temperature near the seafloor.

In addition, we will deploy one mooring equipped with temperature sensors to record the temperature anomaly from the hydrothermal heat flux into the plume, as well as current meters to record the flow direction and amplitude, within one kilometer distance from the vent. This mooring will likewise be recovered after one year of recording time. A full depth CTD cast will be performed at the mooring site, with water sampling for noble gas analysis back in the home lab. The isotope ration of the noble gas helium is a very sensitive tracer for hydrothermal signals in the water column and will, jointly with the temperature profile from the CTD, be used to establish the plume signal at the time of the mooring deployment.

Preliminary (expected) results

We do not expect results during PS131, since the instruments need to be recovered in 2023 during PS137 and will only then allow access to the recorded data.

Data management

Mooring data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

Raw seismological data will be archived and published in PANGAEA within two years after the end of the cruise at the latest. Time-corrected miniseed archives of the seismological data will be submitted to GEOFON from where they are accessible with seismological data base query tools. By default, the CC-BY license will be applied

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

This expedition was supported by the Helmholtz Research Programme “Changing Earth – Sustaining our Future” Topic 2, Subtopic 2.3.

In all publications based on this expedition, the Grant No. AWI_PS131_03 will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

References

Edmonds HN, Michael PJ, Baker ET, Connelly DP, Snow JE, Langmuir CH, Dick HJB, Mu R, German CR, Graham DW (2003) Discovery of abundant hydrothermal venting on the ultraslow-spreading Gakkel ridge in the Arctic Ocean. Nature, 421, https://doi.org/10.1038/nature01351.

Meier M, Schlindwein V (2018), First In Situ Seismic Record of Spreading Events at the Ultraslow Spreading Southwest Indian Ridge. Geophysical Research Letters, 45, https://doi.org/10.1029/2018GL079928.

8. WATER VAPOUR, CLOUD LIQUID WATER, AND SURFACE EMISSIVITY

Gunnar Spreen[1] (Co-PI), Janna Rückert[1], Andreas Walbröl[2]
Not on board: Kerstin Ebell[2] (PI), Mario Mech[2] (Co-PI)

[1]DE.UNI-Bremen
[2]DE.UNI-Köln

Grant-No. AWI_PS131_11

Outline

Water vapour, cloud liquid water, and microwave surface emissivity are measured and analysed as part of the *Polarstern* secondary-use project *Water Vapour, Cloud Liquid Water, and Surface Emissivity over the Arctic Marginal Ice Zone in Summer* (WALSEMA). This work will enhance the observational data base of key climate variables in the Arctic, i.e., here atmospheric integrated water vapour (IWV) and liquid water path (LWP). Clouds and water vapour play a crucial role in the Arctic climate system and are closely intertwined with the complex feedback mechanisms resulting in the so-called Arctic Amplification, i.e., the enhanced increase in Arctic near-surface air temperature compared to the global mean temperature rise. However, large uncertainties still exist in the governing processes which can be partly attributed to a lack of reliable observations. While ground-based reference observations are performed at a few Arctic land sites, observations over the Arctic Ocean and sea ice are even more limited. By conducting the WALSEMA measurements, we will be able to characterise summertime atmospheric water vapour and liquid water path in the Fram Strait and western Nansen Basin over open ocean (O), marginal sea ice (M), and pack ice (I) and complement observations of past expeditions in the Arctic Ocean.

We will operate two microwave (MW) radiometers as well as infrared and visual cameras (sky and surface) on board of *Polarstern* and will launch additional radiosondes (60 in total). All measurements will be used to evaluate satellite MW retrievals of IWV and LWP for the challenging region of the transition zone from open ocean to pack ice. To allow the evaluation of surface contributions the MW, radiometers will occasionally be pointed away from the sky to the ocean and ice surfaces. The measurements along the O-M-I transect will allow to further investigate potential gradients in the atmospheric variables related to the varying surface conditions.

Objectives

Objective 1: Water vapour in the summertime Arctic

We aim to continuously characterise atmospheric water vapour, i.e., IWV and the vertical water vapour profile, in the Fram Strait and the adjacent Arctic Ocean/sea ice region. The impact of different surface conditions, i.e., open ocean, marginal sea ice zone, ice pack, on the atmospheric water vapour will be assessed and potential gradients in water vapour analysed. The research questions are:

Q1: What is the spatio-temporal variability of summertime integrated water vapour and of the water vapour profile in the Fram Strait and adjacent Arctic Ocean/sea ice region?

Q2: How do surface conditions, i.e., open ocean, marginal sea ice zone, and sea ice, influence the atmospheric water vapour content? Can we identify a surface signal or is the coupling to the surface rather masked by large-scale transport mechanisms of water vapour?

To tackle these two questions, we will synergetically exploit the measurements of both MW radiometers, the IR/visual cameras and also combine them with radiosonde and satellite information. Objective 1 is also closely coupled to the research question Q4 of ATWAICE: "How does sea ice heterogeneity in turn affect the turbulent heat fluxes in the atmospheric boundary layer along the ice edge […]". Here, we will focus on the impact of turbulent heat fluxes of water vapour in the atmospheric boundary layer.

Objective 2: Variability of summertime Arctic liquid-bearing clouds

With objective 2, we aim to improve our understanding of liquid-containing clouds over the Fram Strait and Western Nansen Basin. Long-term LWP measurements are already provided at the research station AWIPEV at Ny-Ålesund (Svalbard). However, we expect that the liquid cloud characteristics will be quite different over the open ocean and will also be impacted by the underlying surface. Thus the research questions are:

Q3: What is the spatio-temporal variability of LWP of summertime Arctic clouds in the Fram Strait and Western Nansen Basin?

Q4: How is LWP coupled to the surface conditions and water vapour availability? (link to Q2)

In this way, we also complement the atmospheric studies planned within ATWAICE (by TROPOS, Leipzig), which will focus on aerosols (concentration/properties) with a special interest on new particle formation and the origin and source of cloud condensation nuclei. The sky infrared and optical cameras together with the *Polarstern* meteorological measurements will help to evaluate the sky conditions.

Objective 3: Surface emissivity in the microwave spectrum

We will perform regular measurements of the surface emissivity by downward looking HATPRO and MiRAC-P MW radiometers in connection with measurements by IR and visual cameras to characterise the surface properties.

Q5: What is the spatio-temporal variability of MW emissivity of sea ice and ocean in the Fram Strait and adjacent Arctic Ocean/sea ice region?

Q6: How much does the variability in surface emissivity caused by different surface conditions, i.e., open ocean, marginal sea ice zone and ice pack, influence the MW radiometer satellite retrievals of IWV?

This objective is also closely linked to **Q2** "How do surface conditions, i.e., open ocean, marginal sea ice zone and sea ice, influence the atmospheric water vapour content?". In addition to the upward looking IWV microwave radiometer measurements, also downward looking radiometer measurements and observations of the surface conditions by IR/visual cameras are needed to characterise the surface conditions.

Work at sea

Two microwave radiometers (HATPRO, MiRAC-P) and upward (sky) and downward (surface) infrared (IR) and visual cameras will be operated on board of *Polarstern* (surface camera IR:

InfraTec VarioCAM HDx 625; visual GoPro Hero10). They will be installed at the railing of one of the higher decks of *Polarstern* (Peildeck) to have a clear sky view and side view (30°–60°) of the ocean/sea ice. Before leaving Bremerhaven, both microwave radiometers (MWRs) need to be calibrated with liquid nitrogen. In order to ensure high quality measurements, another liquid nitrogen calibration will be performed for both MWRs during the cruise when *Polarstern* is on station. In order to remove salty sea spray or frost from the radome and lenses of the instruments, they need to be cleaned at least once a day. Preliminary analysis of the MWR and camera data will be performed on a daily basis. The MWR measurements will be monitored and compared to simulations with the PAMTRA forward simulator tool (Mech et al., 2020) based on the radiosonde ascents performed during the cruise. For the objectives 1 and 2, the MWRs will be operated in the "Atmospheric Mode" (upward looking), for objective 3 in the "Surface Mode" (downward looking).

Objectives 1 and 2: Water vapour and liquid clouds

Most of the time, the MWRs will point in zenith direction (Atmospheric Mode) and measure the emitted radiance by the atmosphere in terms of brightness temperature (BTs). The BTs at the different frequencies will be regularly monitored to ensure the correct operation of the instruments.

Based on the BTs at 22.24–31.4 GHz and around 183 GHz, IWV and atmospheric humidity profiles will be retrieved. LWP will be derived from the seven BTs between 22.24–31.4 GHz and atmospheric temperature profiles using the information between 51.26–58.00 GHz. In this way, IWV, LWP, and profile information of temperature and water vapour in particular in the atmospheric boundary layer (ABL) will be continuously (~1 s resolution) provided along the track of *Polarstern*.

Since the retrieved temperature and water vapour profiles provide vertical information with a coarse resolution (but temporally highly resolved), they will be complemented by radiosonde measurements providing a high vertical resolution (but only a very coarse temporal coverage). In addition to the regular daily sounding by the German Weather Service (DWD), a second sounding will be performed by WALSEMA resulting in a sounding frequency of 12 h. During the transects along the open water, marginal ice zone and ice pack, when larger gradients in IWV can be expected, additional soundings will be launched (up to 3-hourly) to better capture this transition and the potential impact on the ABL. Based on the forecast of the onboard DWD meteorologist, potentially interesting periods like warm air intrusions or atmospheric rivers will be identified and additional radiosondes launched during these intense observation periods (IOPs). As water vapour can change by more than 100 % within a few hours during events such as atmospheric rivers (Crewell et al., 2021) a higher frequency of soundings is necessary to capture the potential variability of water vapour. The additional soundings will also be beneficial for the atmospheric measurement programme of ATWAICE.

Additionally, wide opening angle (fish-eye) visual and IR sky cameras will be operated to analyse the sky cloud conditions. Automatic cloud coverage extraction from the camera images will be performed in future.

With this data set of high-quality measurements, we will be able to subsequently characterise water vapour, liquid water path and their variability in the Fram Strait and Arctic Ocean in summer (Q1 and Q3). Through the measurements along the O-M-I transects which will be supported by enhanced observations, we can address questions Q2 and Q4. In order to set the local observations in a larger scale context, we will also make use of satellite data and observations from other supersites, e.g., Ny-Ålesund. In particular for IWV, transport patterns can be identified from satellite images and will help in the interpretation of the local signals.

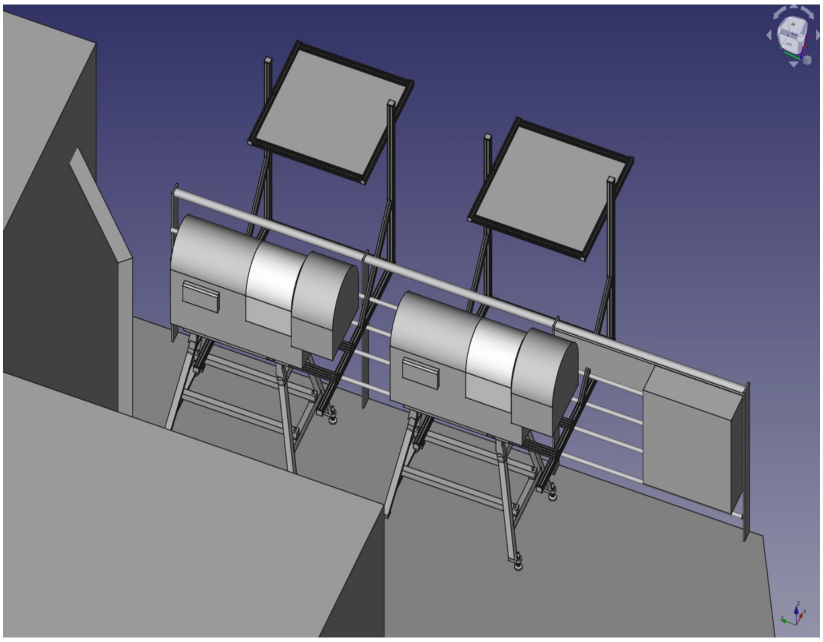


Fig. 8.1: Sketch of both microwave radiometers with mirror systems

Objective 3: Surface emissivity

On a regular basis, the MWRs will be pointed towards the ocean/sea ice surface using a rotatable mirror fixed to the stand of each MWR (i.e., HATPRO and MiRAC-P) directing the signal from the surface over the railing into the MWRs' antennas (see Fig. 8.1 for sketch). Due to a rotatable mirror, different incidence angles can be realised. During the cruises over open ocean, the pointing towards the surface will be done on an irregular basis whenever the situation allows (i.e., swell and wind). In the marginal sea ice zone and the packed ice, the radiometer will point towards the surface every hour for five minutes. Especially when *Polarstern* is moving through sea ice and especially in the MIZ, it is important to perform the surface measurements with higher temporal resolution as the surface emissivity is very variable. In the so-called "enhanced Surface Mode" when *Polarstern* is on station, the observations to the surface will be more extensive under different observation angles. We are aware that these measurements will only allow us to estimate the total emissivity, and no polarisation information will be available. However, they can aid synergetic multi-parameter satellite retrievals for atmosphere and sea ice properties like, e.g., the one from Scarlat et al. (2020) or IWV only satellite retrievals like in Triana-Goméz et al. (2020).

Next to the MWRs, a setup of the combined infrared and visual camera will be installed pointing towards the surface under a 45° angle. With an opening angle of about 25° for the IR camera, this setup will fully cover the Field of View (FOV) of the MWRs. With a spatial resolution of more than 10 cm, the IR and visual cameras will also provide sub-footprint scale surface variability for the MWR measurements, which is essential to interpret the MWR data. The camera acquisitions will be taken every 10 seconds, which allows continuous coverage of the surface conditions. These continuous surface characterisation measurements can be used to interpolate surface emissivity information when the MWRs are in "Atmospheric Mode" configuration. I. e., MW emissivities of typical surface classes like sea ice, open water, melt ponds will be measured during "Surface Mode" MWR acquisitions and the IR/visual camera data will be used to determine the fractions of these surface classes along the *Polarstern* track. The combination of the two will allow to estimate surface emission on a satellite footprint scale (5–50 km).

During ice stations, we will perform measurements of the physical properties of sea ice and snow (i.e., during summer more likely of the surface scattering layer) within the footprints of the two MWRs (salinity and temperature profiles from ice cores and snow pits). This will allow us to better analyse the surface emissivity variability based on surface conditions. A *Stevens HydraProbe* will be used to measure the electromagnetic properties (permittivity) of the snow (if any snow/scattering layer of significant height is present). From this the liquid water content of the snow it can be inferred, which is one of the dominant properties determining the surface MW signal. These measurements will be conducted in collaboration and coordination with the sea ice team from the ATWAICE project.

Deployment of equipment

We will deploy two microwave radiometers and IR/visual cameras on board the *Polarstern*. Both MWRs are of similar size with the approximate dimensions 1.2 m x 0.7 m x 1.5 m (L x W x H). For the Surface Mode, bars holding metal mirrors will be attached to the stand of the radiometers on the side towards the railing on the starboard side. The mirrors will be in a height of approximately 2.0 m directly of the railing. The surface cameras are fixed on a tripod with approximate diameter of 1 m and 1.5 m height. The sky cameras will be most likely be installed at the railing. The instrumentation will be installed on the upper pilot deck close to the railing starboard side. This is crucial in order to be able to change the MWR measurements from Atmospheric to Surface Mode.

Radiosondes will be launched in collaboration with DWD and the same facilities used.

Special requirements

For the calibration of the MWRs at the beginning and in the middle of the cruise, liquid nitrogen from the onboard liquid nitrogen generator is needed, i.e., ~100 L for each calibration. In addition to the regular radiosoundings planned by the German Weather Service, we will launch an additional, second sounding per day, i.e. resulting in a sounding every 12 h. During intense observation periods, the frequency of radiosonde launches will be enhanced, e.g., during the transects over open ocean – marginal ice zone – ice pack. This activity is agreed on and will be coordinated with the German Weather Service.

Preliminary (expected) results

The conducted measurements will allow to achieve objects 1 to 3 described above and the goals mentioned therein. In short, we will be able to characterise summertime atmospheric water vapour and liquid water path in the Fram Strait and western Nansen Basin over open ocean, marginal sea ice, and pack ice and complement observations of past expeditions in the Arctic Ocean, in particular, a continues IWV, LWP, and MW surface emissivity time series from MW radiometers. Supporting continuous infrared and visual data of the sky and surface will allow to characterise the cloud cover and surface type composition (sea ice fraction and temperature field). The additional radiosonde launches will allow to better temporarily resolve synoptic atmospheric events like, e.g., warm air intrusions or cold air outbreaks and the atmospheric gradients over the marginal ice zone. They will also help to have well calibrated MW radiometer IWV and LWP time series.

This effort is part of and contributing to the Transregional Collaborative Research Centre TRR-172 "ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms $(AC)^3$" funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation). The obtained datasets will lead to and be used in several peer-reviewed publications. The two berths granted for this project are filled by PhD candidates and it will help their PhD work and scientific career.

Data management

Immediately after the cruise and return of the instruments, all sensor data will be copied to the University of Cologne computing center. The processed sensor and radiosonde data will be uploaded to the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) when processing and quality checking has been completed within 2 years after the cruise. By default, the CC-BY license will be applied. The metadata will be openly visible, but the processed sensor data will be given a 1-year moratorium to allow publication of the scientific results by the applicants - in line with previous practice. Data will be made directly available to the ATWAICE team and other collaborating partners. In particular, the time series of the atmospheric measurements will be provided as “quicklooks” which are open to the public.

This WALSEMA project is supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) through the Transregional Collaborative Research Centre TRR-172 “ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes, and Feedback Mechanisms (AC)^3” (grant 268020496).

In all publications based on this expedition, the Grant No. AWI_PS131_11 will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

References

Crewell S, Ebell K, Konjari P, Mech M, Nomokonova T, Radovan A, Strack D, Triana-Gómez AM, Noël S, Scarlat R, Spreen G, Maturilli M, Rinke A, Gorodetskaya I, Viceto C, August T, Schröder M (2021) A systematic assessment of water vapor products in the Arctic: from instantaneous measurements to monthly means. Atmos. Meas. Tech., 14, 4829–4856, https://doi.org/10.5194/amt-14-4829-2021.

Mech M, Maahn M, Kneifel S, Ori D, Orlandi E, Kollias P, Schemann V, Crewell S (2020) PAMTRA 1.0: The Passive and Active Microwave radiative TRAnsfer tool for simulating radiometer and radar measurements of the cloudy atmosphere. Geoscientific Model Development, 13, 4229–4251, https://doi.org/10.5194/gmd-13-4229-2020.

Scarlat RC, Spreen G, Heygster G, Huntemann M, Patilea C, Pedersen LT, Saldo R (2020) Sea Ice and Atmospheric Parameter Retrieval From Satellite Microwave Radiometers: Synergy of AMSR2 and SMOS Compared With the CIMR Candidate Mission. J. Geophys. Res. Oceans, 125(3), e2019JC015749, https://doi.org/10.1029/2019JC015749.

Triana-Gómez AM, Heygster G, Melsheimer C, Spreen G, Negusini M, Petkov BH (2020) Improved water vapour retrieval from AMSU-B and MHS in the Arctic. Atmos. Meas. Tech., 13, 3697–3715. https://doi.org/10.5194/amt-13-3697-2020.

9. GREENHOUSE GAS FLUXES AT OCEAN-SEA ICE INTERFACES IN THE ARCTIC OCEAN (FLUX-ON-SITE)

Damian L. Arévalo-Martínez, Sina S. Pinter DE.GEOMAR
Not on board:
Hermann W. Bange

Grant-No. AWI_PS131_08

Outline

In the Arctic Ocean, warming and decrease in sea ice coverage are expected to affect the cycling pathways and atmospheric emissions of greenhouse gases (GHG) such as N_2O and CH_4. Yet, the future development of these processes is highly uncertain since gathering observations is challenging due to extreme weather conditions and technical constraints posed by sea ice properties. To amend this deficit, we will carry out an extensive multidisciplinary investigation of the magnitude, driving mechanisms and variability of N_2O and CH_4 fluxes across sea-ice-air interfaces in the Nansen Basin and Fram Strait. The main foci of the project are (i) the gas exchange across interfaces, (ii) the emissions from the region and their contribution to the global GHG budget, (iii) the role of submesoscale dynamics in shaping the water column variability of N_2O and CH_4, and (iv) the temporal-spatial variability of gas source-sink dynamics in the Fram strait.

Objectives

Considering the substantial lack of understanding in regard to the exchange of N_2O and CH_4 across ocean-sea ice-air interfaces in the Arctic Ocean, FLUX-ON-SITE aims to elucidate the magnitude, driving mechanisms and variability of their fluxes across the ocean-sea ice-air interfaces in the Nansen Basin and Fram Strait. For this to end, we will employ state-of-the-art platforms for simultaneous measurements of both gases in sea water, ice and the overlying atmosphere. The specific objectives of FLUX-ON-SITE are:

- Ascertain the large-scale spatial and temporal variability of N_2O and CH_4 fluxes through sea-ice-air interfaces in response to different ice melt conditions.
- Constrain the regional N_2O and CH_4 emissions from the in the Nansen Basin and Fram Strait and establish their relevance for the global oceanic budget.
- Assess the role of submesoscale dynamics on the water column variability of N_2O and CH_4
- Evaluate the relative importance of local vs. remote large-scale oceanographic processes and their spatial variability for the budget of N_2O and CH_4 at the Fram Strait.
- Quantify mixing-corrected net community production estimates based on collocated high-resolution Ar/O_2 and N_2O measurements (see also Chapter 6).

Work at sea

In order to achieve the project's goals, we will combine several state-of-the-art measurement methods for GHGs (Fig. 9.1):

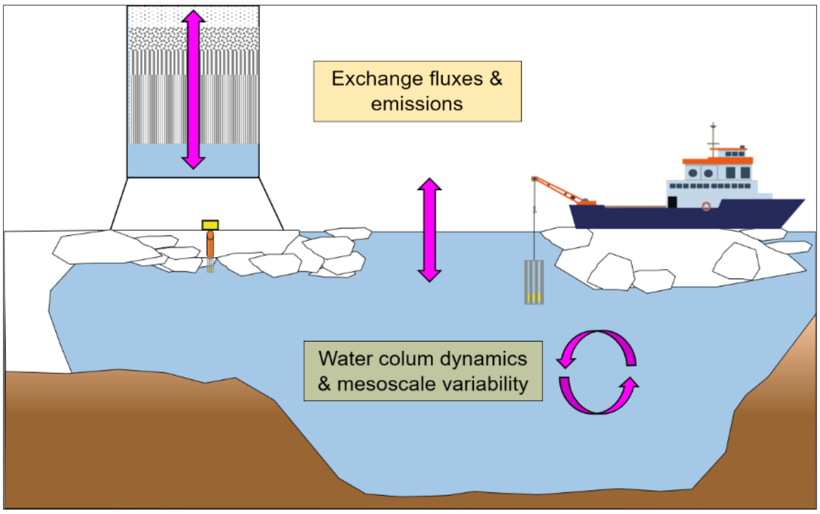


Fig. 9.1: Overview of the planned sampling strategy. The insert shows a schematic view of the sea-ice-air interfaces that will be investigated during ice stations.

- Continuous near-surface measurements: We will conduct along-track measurements of dissolved N_2O and CH_4 in surface seawater by means of an autonomous setup consisting on spectroscopic analysers coupled to a continuous air/seawater gas equilibrator (see e.g. Arévalo-Martínez et al., 2019). Simultaneously, measurements of atmospheric air will be carried out by an additional analyser running on parallel and drawing air from a clean intake near the vessel's bow.
- Discrete water column sampling: Samples for measurements of dissolved N_2O and CH_4 concentrations in the water column will be collected from regular CTD stations (total volume per depth 1.5 L). Gas samples will be preserved on board and shipped to Kiel (Germany) directly after the cruise in order to proceed with the measurements via a gas chromatographic method. The measurements will be conducted at the chemical oceanography department of GEOMAR Helmholtz Centre for Ocean Research Kiel.
- Ice stations: We will conduct a comprehensive sea ice measuring programme for N_2O and CH_4 during the ice stations planned for ATWAICE:
- *In-situ* atmospheric measurements: We will combine the underway atmospheric measurements (see above) with the deployment of a portable version of the trace gas analyser during ice stations. This will allow us to detect slight changes in N_2O and CH_4 during the ice stations and will serve as a cross-check for the ship-borne atmospheric measurements that will be carried out simultaneously.
- Ice coring: Ice cores will be extracted with a Kovacs Mark II (or similar) ice corer (9 cm diameter) in cooperation with the sea ice group at AWI (Chapter 3). Following the core extraction (in duplicates), 10 cm sections will be sliced and directly packed into 5 L gas-tight bags which allows for manually evacuating the remaining air before being transported to the ship for further processing. Slicing can also be done on board if not possible on site, as long the ice core is packed and transported in gas-tight bag. Once on board, ice samples will be allowed to thaw under ambient temperature and the resulting headspace will be progressively removed by means of a low-flow air pump

(see Randall et al., 2012; Miller et al., 2015). Upon full melting, the resulting water will be transferred to 20 mL glass vials (in triplicates) which then will be preserved and shipped to Kiel (Germany) along with the discrete samples from the CTD. The sampling will be coordinated with other groups on board such that information on basic parameters like temperature and salinity within the cores can be shared.

- Under-ice sampling: N_2O and CH_4 concentrations in water directly beneath (and in contact with) sea ice under undisturbed conditions, will be determined by sampling with a portable pumping system allowing us to collect discrete samples at 10, 25, 50, 100 and 150 cm below bottom ice. The seawater is brought to the surface through a silicon/Tygon tubing, so that discrete samples for gas analysis can be collected. Triplicate, bubble-free samples will be taken at each depth by filling 20 mL glass vials, which then will be further treated as explained above. This sampling will directly follow the ice core extraction at a given site in order to spatially couple seawater and bulk ice measurements.

Preliminary (expected) results

We expect large, yet spatially variable N_2O and CH_4 flux gradients within relatively small areas. By resolving these scales of variability (sub-km), we expect to contribute to an improved representation of GHG sea-ice air fluxes in climate models, and more accurate estimates of the relative weight of this area for the Arctic and global N_2O and CH_4 budgets. Furthermore, we expect significant physically-driven changes in the basin-wide distribution of N_2O and CH_4. In particular, we expect to be able to determine the influence of the polar outflow on the source/sink dynamics of GHG in the adjacent subpolar North Atlantic.

Data management

Environmental data will be archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

Additionally, N_2O and CH_4 data will be archived in the MEMENTO database (https://memento.geomar.de), which is a widely used tool for international researchers working on trace gas biogeochemistry (Kock and Bange, 2015).

In all publications based on this expedition, the Grant No. AWI_PS131_08 will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

References

Arévalo-Martínez D L, Steinhoff T, Brandt P, Körtzinger A, Lamont T, Rehder G, Bange HW (2019) N_2O Emissions From the Northern Benguela Upwelling System. Geophysical Research Letters, 46(6), 3317–3326. https://doi.org/10.1029/2018GL081648.

Kock A, Bange HW (2015) Counting the ocean's greenhouse gas emissions. Eos, 96, 10–13, https://doi.org/10.1029/2015EO023665.

Miller LA, Fripiat F, Else BGT, Bowman JS, Brown KA, Collins RE, Ewert M, Fransson A, Gosselin M, Lannuzel D, Meiners KM, Michel C, Nushioka J, Nomura D, Papadimitriou S, Rusell LM, Sorensen LL, Thomas, DN, Tison J-L, van Leuwe M, Vancoppenolle M, Wolff, EW, Zhou J (2015) Methods for biogeochemical studies of sea ice: The state of the art, caveats, and recommendations. Elementa, 3, 38, https://doi:10.12952/journal.elementa.000038.

Randall K, Scarratt M, Levasseur M, Michaud S, Xie H, Gosselin M (2012) First measurements of nitrous oxide in Arctic sea ice. Journal of Geophysical Research: Oceans, 117(5), 2–9. https://doi.org/10.1029/2011JC007340.

10. ICEJELLY: INFLUENCE OF SEA-ICE AND SUB-MESOSCALE OCEANOGRAPHY ON JELLY DISTRIBUTIONS AND COMMUNITIES

Charlotte Havermans (not on board), Meret Jucker, Ayla Murray DE.AWI

Grant No. AWI_PS131_10

Objectives

In the Arctic Ocean (AO), environmental changes are occurring at an unprecedented pace. The AO is undergoing a pronounced sea-ice thinning (Krumpen et al., 2015) and a decline of the overall summer sea ice extent, with a prediction of nearly ice-free summers within the next 25 years (Overland & Wang, 2013). There has been a growing influence of warmer Atlantic water, entering the AO via the eastern Fram Strait and the Barents Sea, a phenomenon referred to as "Atlantification" (Polyakov et al., 2017). This warm-water inflow carries along nutrients and advected Atlantic-boreal species (Wassmann et al., 2015). Due to these changes, the AO has already experienced noticeable changes in species composition as well as poleward range expansions of species of Atlantic origin (e.g., Neukermans et al., 2018; Schröter et al., 2019; Haug et al., 2017). Hence, a large-scale understanding of Arctic marine biodiversity is particularly pressing. Accurate distribution records and community assessments, combining traditional and molecular methods, are needed to predict and monitor community shifts and potential invaders in the AO (Lacoursière-Roussel et al., 2018).

Gelatinous zooplankton, hereafter also referred to "GZP" or "jellies", are fragile, soft-bodied organisms that lack an exoskeleton or hard body parts. It groups together a number of phylogenetically very distant taxa: *ctenophores, scyphomedusae, hydrozoans* (including colonial *siphonophores*) and pelagic tunicates (e.g. *appendicularians*). In contrast to crustacean zooplankton, relatively little is known about Arctic GZP beyond records of occurrence and regional species lists (e.g., Kosobokova et al., 2011). As a rule, rather than the exception, jellies are discarded from quantitative plankton surveys and when included in pelagic studies, data are limited to coarse taxonomic levels (Geoffroy et al., 2018). Hence, comparable regional abundance data of GZP in the Arctic are missing, let alone temporal datasets over several years to monitor potential gelatinous regime shifts as those witnessed in the Antarctic, with the notorious krill-to-salp shift (Atkinson et al., 2019). Nonetheless, pioneering work with underwater imaging and under-ice trawls showed *ctenophores* and *hydromedusae* to be particularly abundant in several Arctic Ocean basins (Raskoff et al., 2005, 2010; Purcell et al., 2010; David et al., 2015). *Appendicularians* are among the highest biomass of non-copepod zooplankton taxa, and thrive at the margins of polynyas and at the ice edge (Deibel et al., 2005, 2017). They significantly contribute to vertical carbon export with their discarded houses and faecal pellets (Deibel et al., 2005). These observations further corroborate the importance of this faunal group in the Arctic ecosystem, which may well be a jelly-dominated ecosystem.

How further warming and sea-ice thinning will affect Arctic GZP communities will critically depend on whether dominant species are cold-adaptive or bound to sea ice as habitat, for shelter or for food supply (through the sea-ice algal production). Large populations of jellies, in particular *ctenophores*, have been observed under the ice in the Fram Strait (PS107, C. Havermans, pers. obs.) and the central Arctic region (MOSAiC ROV videos). We can currently not explain these high abundances under the ice because of a lack of knowledge on Arctic jelly ecology (e.g., behaviour, feeding habits, potential overwintering strategies). Therefore, it is essential to evaluate the role of sea ice in structuring GZP communities and shaping their distributions in order to make reliable predictions on the impact of further sea-ice decline.

Variation in distribution and abundance of GZP often relate to physical water properties and features. GZP are known to aggregate horizontally as a result of their affinities to particular water masses (Graham et al., 2001), with highest densities of GZP often occurring at fronts or halo/thermoclines (Raskoff et al., 2005). Pioneering studies using ROV, SCUBA diving and depth-stratified nets could link species distributions with the complex and multi-origin water layers typical of the AO, characterised by strong discontinuities in temperature and salinity (Raskoff et al., 2005; Purcell et al., 2010). The interaction of warm, salty Atlantic Water and cold, fresher Polar Water, as well as meltwater from sea-ice melt, generates sharp sub-mesoscale fronts (von Appen et al., 2018). Since fronts and eddies are ubiquitous in the near-surface AO, it is important to determine the interaction between physical oceanography and GZP small-scale distributions for determining the environmental niche of the different species and identifying the variation in GZP community composition.

With the ICE-Jelly Jelly research programme, we aim to collect species-level GZP data along a sea-ice gradient and at sub-mesoscale spatial scales, with a focus on particular features such as the halocline, fronts and eddies. To do so, we will combine depth-stratified net sampling with non-invasive methods including environmental DNA (eDNA) and optical (imaging) surveys with the Underwater Vision Profiler (UVP). Our integrative surveys will allow us to study how jelly aggregations, distributions and feeding habits change from open ocean across the Marginal Ice Zone (MIZ) to the pack ice. These datasets of unprecedented spatial resolution will significantly improve our understanding of GZP dynamics, ecology and allow us to improve predictions on future GZP communities.

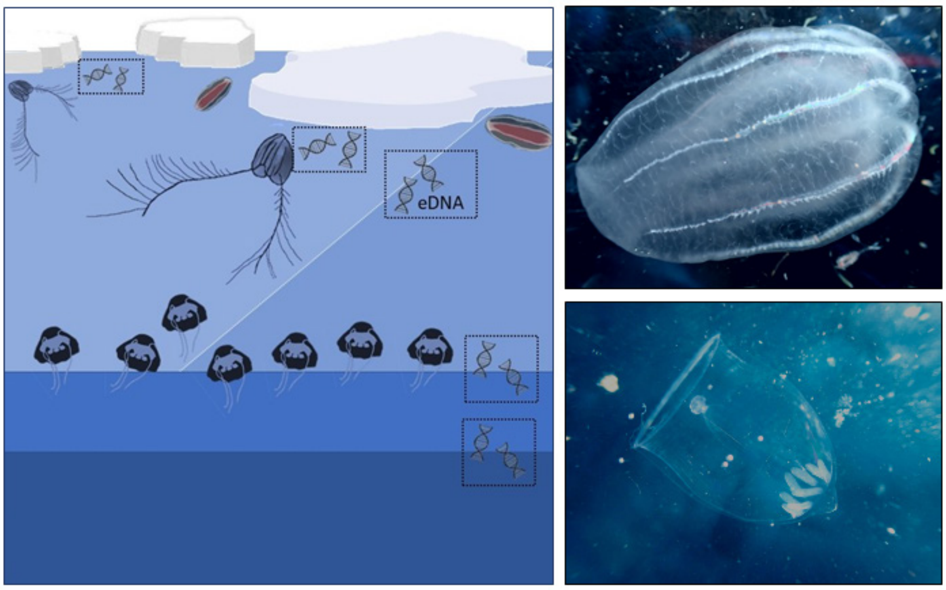


Fig. 10.1: Left: A schematic drawing illustrating the small-scale distributions of GZP we aim to assess with the ICE-Jelly programme (Drawing: Charlotte Havermans); right: Arctic GZP species known to be abundant under the ice: the ctenophore Beroe cucumis and the hydrozoan Aglantha digitale (Photos: Charlotte Havermans)

The objectives of the ICE-Jelly project are:

- Study species richness, community composition and small-scale distributions of GZP and link these to environmental parameters. Species distributions will be assessed vertically and along sea-ice and sub-mesoscale hydrographic gradients – plankton net catches, DNA barcoding, eDNA metabarcoding, UVP surveys;
- Obtain and compare GZP abundance data from different sampling methods across different hydrographic and sea-ice gradients – plankton net catches, UVP surveys;
- Elucidate the trophic role of dominant jellies in local Arctic food webs and their reliance on sea-ice associated food sources – plankton net catches, biomarker and molecular diet analyses;
- Identify GZP "bioregions" based on data from the different sampling methods in the various sampling areas of open water, MIZ, and pack ice – joint species distribution and community distribution modelling;
- Compare GZP species composition at the same localities over several years and link this to local hydrography and other environmental parameters – eDNA time series (2019 – 2022), plankton net catches.

Work at sea

The working area will consist of different focus areas: i) the West Spitsbergen Current in Fram Strait, ii) the transition from open waters to the MIZ and the pack ice, and iii) the 79N glacier calving front. We will identify our sampling localities based on the small-scale oceanographic features detected with the topAWI and target localities along the encountered sea-ice gradients. At these locally identified gradients, we will carry out net sampling with Multinet and Bongonet deployments, for depth-stratified GZP community assessment and the collection of animals for molecular and trophic analyses, respectively. We will filter water from the CTD bottles, sampled at various depths, for eDNA metabarcoding analyses. Small-scale distribution of smaller-sized GZP will also be characterised with the UVP profiles obtained at each station (with the UVP attached to the CTD rosette). At several Fram Strait HAUSGARTEN stations (N4, S3, HG-IV), we will carry out eDNA water sampling with the CTD at various depths (from surface to seafloor) to carry on a time series of eDNA characterisation over several years (2019 – PS121, 2020 – MSM95, 2021 – PS126), which will allow us to assess inter-annual variation of Arctic GZP communities. In areas with heavy sea ice cover (YP-I and AURORA), where no nets and CTD/UVP can be deployed, we will use the opportunity to work at the planned ice stations to sample water from the under-ice interface (through drill holes) for eDNA studies, deploy a small hand net and an underwater camera for video footages of jellies observed under the ice.

Net sampling

Macrozooplankton, including GZP, will be collected using a variety of net deployments for species identification, abundance data and molecular/trophic analyses. Stratified vertical hauls with the Midi-Multi-Net will allow us to obtain information on the vertical distribution of jellies. The Midi-MN has a 0.25 m^2 mouth opening and an opening-closing mechanism with 5 net bags with a 150 µm mesh size, and will be vertically hauled at 0.5 m/s. Oblique tows with Bongo nets (0.3 m^2 opening, 300 – 500 µm mesh size) will allow to catch the larger animals. Bongo nets are equipped with a large non-filtering cod-end and a V-Fin depressor and will be towed obliquely at a ship's speed of 2 knots. A flowmeter attached to the nets will allow to calculate the volume of water sampled. Jelly abundances will be calculated based on the volume of water sampled and the number of jellies counted per species. Freshly caught jellies will be identified to the lowest taxonomic level possible and photographed for posterior identification, with particular attention to identification features (e.g. gonads, manubrium, shape of the umbrella, tentacle arrangement, oral arms) depending on the taxonomic group. Specimens will be measured and preserved in ethanol (voucher specimens) or frozen at –80° C. They will be used for DNA barcoding (to confirm morphological identification), molecular diet analyses and biomarker studies (to elucidate the trophic role of dominant species).

Optical surveys

The Underwater Vision Profiler (UVP) images, enumerates and measures zooplankton (> 0.5 mm), as well as particle aggregates (> 60 µm) such as marine snow, quantifying their vertical distribution *in situ* (Picheral et al., 2010). It will be mounted on the CTD-rosette, imaging the plankton during its descent, hence each image is associated with the environmental variables at corresponding depths. This will allow a quantitative assessment of smaller-sized GZP abundances. The UVP consists of a pressure-safe housing and two LED lights, coupled to a camera. It efficiently images smaller-sized plankton and particles of ca. 0.1 to 10 mm, each time illuminating a volume of approximately 1 L, when being deployed vertically in the water column (Picheral et al., 2010). Six to eleven images are taken per second, which are immediately processed during the downcast, i.e. objects are counted, sized and saved, together with depth and other information.

At the sea-ice stations, a GoPro™ underwater camera will be deployed in order to validate eDNA results of jellies observed under the ice.

Water sampling for eDNA analyses

Water samples of 2 L will be collected in triplicates from the CTD rosette water sampler casts, at different depth intervals, corresponding to the depth layers sampled with the stratified Multi-Net hauls. At the ice stations, water will be sampled by deploying a 2.5 L Niskin bottle manually through a hole in the ice. This will also be done in triplicates, at different localities on the ice floe. Water will be immediately filtered on board through Sterivex cellulose filters of 0.2 µm average pore size. An extraction blank will be filtered in the same way after filtration at each station to monitor contamination. Filters containing eDNA will be frozen at –80°C. These will be processed further at our eDNA laboratory in the AWI.

Expected results

GZP species composition and abundances will be determined for each net haul and linked with oceanographic features identified in the CTD and topAWI (TRIAXUS) profiles. Their vertical distribution and diversity will also be assessed based on the optical datasets and the results of the eDNA studies from water samples, generating a comprehensive overview of the different GZP communities and small-scale distributions. These datasets will also allow us to build a presence dataset of GZP, including information on the environmental parameters. These will be fed into distribution/niche models to define the current Arctic GZP communities, but also to predict how climate and environmental change will impact the different species in the future. Our modelling approach will also enable us to identify GZP “bioregions” based on data from the different sampling methods.

The sea-ice work at the ice stations, consisting of under ice water sampling for eDNA, deployment of an underwater camera and collection of GZP with a small hand net, will allow us to investigate whether we encounter unique GZP communities under the pack ice, and which species are dominant in the under-ice surface layers. This, together with trophic analyses on the specimens collected, will allow us to identify GZP species that are bound to sea ice as a habitat or for food supply.

The results of our eDNA metabarcoding analyses, validated through depth-stratified net catches, at the Fram Strait HAUSGARTEN stations will contribute to our eDNA time series at these sites. This effort has been initiated in 2019, and will now cover four years, allowing us to assess interannual variation in GZP community composition.

The results of our planned biomarker and molecular diet analyses on dominant jelly species will allow us to elucidate longer-term dietary signals (including those characteristic of ice algae versus pelagic flagellates with marker fatty acids) as well as a full characterization of prey spectrum analysis at species level (DNA metabarcoding of gastric pouch contents).

Jelly specimens will be genetically characterised (or “barcoded”) by sequencing the cytochrome c oxidase subunit 1 (COI), 16S rDNA and 18S rDNA to complement existing reference databases, to assess initial genetic variability of morphospecies and reveal their phylogeographic patterns.

Data management

Zooplankton samples and Sterivex filters for eDNA studies will be archived and stored at the AWI. DNA extracts of jellies and eDNA samples from water column and sediment will be stored at –80° C for up to 10 years after publication of the results (according to the DFG guidelines for good scientific practice). A voucher collection of ethanol preserved jelly specimens, linked to their DNA extracts, will be kept in a repository at the AWI. Geo-referenced environmental data sets such as GZP distribution records and species inventories from net catches will be archived published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea. de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied.

Biogeographic datasets will also feed other databases (e.g. OBIS, GBIF). Acquired optical datasets will be archived in IT storage infrastructures of the AWI, and metadata will be made accessible in PANGAEA, within six months after completion of the expedition. The image datasets from the UVP will be submitted to EcoTaxa (https://ecotaxa.obs-vlfr.fr/), and released as soon as the results are published (up to three years after the expedition).

Molecular data (DNA and RNA data) will be archived, published and disseminated within one of the repositories of the International Nucleotide Sequence Data Collaboration (INSDC, www.insdc.org), comprising EMBL-EBI/ENA, GenBank and DDBJ. Results on eDNA metabarcoding analyses will be published in peer-reviewed journals within three years after the cruise.

Any other data will be submitted to an appropriate long-term archive that provides unique and stable identifiers for the datasets and allows open online access to the data.

This expedition was supported by the Helmholtz Research Programme "Changing Earth – Sustaining our Future" Topic 6, Subtopic 6.1”.

In all publications based on this expedition, the Grant No. AWI_PS131_10 will be quoted and the following publication will be cited:

Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.

References

von Appen WJ, Wekerle C, Hehemann L, Schourup-Kristensen V, Konrad C, Iversen M (2018) Observations of a submesoscale cyclonic filament in the marginal ice zone. Geophysical Research Letters 45, 6141-6149.

Atkinson A, Hill SL, Pakhomov EA, Siegel V, Reiss CS, Loeb VJ, Steinberg DK, Schmidt K, Tarling GA, Gerrish L, Sailley SF (2019) Krill (*Euphausia superba*) distribution contracts southward during rapid regional warming. Nature Climate Change 9, 142-147.

David C, Lange B, Rabe B, Flores H (2015) Community structure of under-ice fauna in the Eurasian central Arctic Ocean in relation to environmental properties of sea-ice habitats. Marine Ecology Progress Series 522: 15-32.

Deibel D, Saunders PA, Acuna JL, Bochdansky AB, Shiga N, Rivkin RB (2005) The role of appendicularian tunicates in the biogenic carbon cycle of three Arctic polynyas. In: Gorsky G, Youngbluth MJ, Deibel D (eds) Reponse of marine ecosystems to global change: Ecological impact of appendicularians. Gordon and Breach, Paris, pp. 327-356.

Deibel D, Saunders P, Stevens C (2017) Seasonal phenology of appendicularian tunicates in the North Water, northern Baffin Bay. Polar Biology 40, 1289-1310.

Geoffroy M, Berge J, Majaneva S, Johnsen G, Langbehn TJ, Cottier F, Mogstad AA, Zolich A, Last K (2018) Increased occurrence of the jellyfish *Periphylla periphylla* in the European high Arctic. Polar Biology 41, 2615-2619.

Graham WM, Pagès F, Hamner WM (2001) A physical context for gelatinous zooplankton aggregations: a review. Hydrobiologia 451, 199-212.

Haug T, Bogstad B, Chierci M, Gjosaeter H, Hallfredsson EH, Age S, Hoines A, Hoel H, Ingvaldsen RB, Jorgensen L, Knutsen T, Loeg H, Naustvoll LJ Rottingen I, Sunnana K (2017) Future harvest of living resources in the Arctic Ocean north of the Nordic and Barents Seas: a review of possibilities and constraints. Fisheries Research 188, 38-57.

Kosobokova KN, Hopcroft RR, Hirche HJ (2011) Patterns of zooplankton diversity through the depths of the Arctic's central basins. Marine Biodiversity 41, 29-50.

Krumpen T, Gerdes R, Haas C, Hendricks S, Herber A, Selyuzhenok V, Smedsrud L, Spreen G (2015) Recent summer sea ice thickness surveys in the Fram Strait and associated volume fluxes. The Cryosphere Discussions 9, 5171-5202.

Lacoursière-Roussel A, Howland K, Normandeau E, Grey EK, Archambault P, Deiner K, Lodge DM, Hernandez C, Leduc N, Bernatchez L (2018) eDNA metabarcoding as a new surveillance approach for coastal Arctic biodiversity. Ecology and Evolution 8, 7763-7777.

Neukermans G, Oziel L, Babin M (2018) Increased intrusion of warming Atlantic water leads to rapid expansion of temperate phytoplankton in the Arctic. Global Change Biology 24, 2545-2553.

Overland JE, Wang M (2013) When will the summer Arctic be nearly sea ice free? Geophysical Research Letters 40, 2097-2101.

Picheral M, Guidi L, Stemmann L, Karl DM, Iddaoud G, Gorsky G (2010) The underwater vision profiler 5: An advanced instrument for high spatial resolution studies of particle size spectra and zooplankton: Underwater vision profiler. Limnology and Oceanography Methods 8, 462-473.

Polyakov IV, Pnyushkov AV, Alkire MB, Ashik IM, Baumann TM, Carmack EC, Goszezko I, Guthrie J, Ivanov VV, Kanzow T, Krishfield R, Kwok R, Sundfjord A, Morison J, Rember R, Yulin A (2017). Greater role for Atlantic inflows on sea-ice loss in the Eurasian Basin of the Arctic Ocean. Science 356, 285-291.

Purcell JE, Hopcroft RR, Kosobokova KN, Whitledge TE (2010) Distribution, abundance, and predation effects of epipelagic ctenophores and jellyfish in the western Arctic Ocean. Deep-Sea Research II 57, 127-135.

Raskoff KA, Hopcroft RR, Kosobokova KN, Youngbluth MJ, Purcell JE (2010) Jellies under ice: ROV observations from the Arctic 2005 Hidden Ocean Expedition. Deep-Sea Research II 57, 111-126.

Raskoff K A, Purcell JE, Hopcroft RR (2005) Gelatinous zooplankton of the Arctic Ocean: in situ observations under the ice. Polar Biology 28, 207-217.

Schröter F, Havermans C, Kraft A, Knüppel N, Beszczynska-Moeller A, Bauerfeind E, Nöthig EM (2019) Evidence of continuing presence of a temperate amphipod in the Fram Strait based on sediment trap time series. Frontiers in Marine Science 6, 311.

Wassmann P (2015) Overarching perspectives of contemporary and future ecosystems in the Arctic

11. GEODETIC-GLACIOLOGICAL INVESTIGATION OF ZACHARIAE ISSTRØM, NORTH-EAST GREENLAND

Katrina Bartek[1], Erik Loebel[2]
Not on board:
Mirko Scheinert[2], Matthias Braun[1]

[1] DE. FAU
[2] DE. TU-Dresden

Grant No. AWI_PS131_09

Objectives

The Greenland Ice Sheet (GrIS) is sensitive to changes in atmospheric and oceanic conditions that occur as a consequence of climate change. Meltwater percolates into and drains the glaciers and finally enters the ocean which influences both global and regional sea levels as well as oceanic circulation patterns. While the **mass balance** was still close to equilibrium in the 1990s, significant mass losses set in thereafter, reaching values above 300 Gt/a in the years 2010 to 2012 and weakening slightly again in the following years (Shepherd et al. 2019, Pörtner et al. 2021). In the period 2005 – 2015, the GrIS alone contributed about 20 % to global mean **sea level rise.** About half of the mass decreases resulted from a decrease in the surface mass balance (SMB) and half from an acceleration in glacier flow (Shepherd et al. 2019, Mouginot et al. 2019).

In the working area, the ice sheet is dominated by the Northeast Greenland Ice Stream (NEGIS), which splits into the three main streams Nioghalvfjerdsbræ, Zachariae Isstrøm and Storstrømmen. Since the beginning of the 21st century, dynamically induced mass loss has been observed for Nioghalvfjerdsbræ and Zachariae Isstrøm (ca. 10 Gt/a between April 2006 and April 2012, Khan et al. 2014). The glacier tongue of Nioghalvfjerdsbræ lost 30 % of its thickness during the period 1999 – 2014 (Mayer et al. 2018). Even greater mass losses occurred at Zachariae Isstrøm. Mouginot et al. (2015) describes the further accelerated retreat of this glacier since 2012 as a result of the extensive dissolution of its offshore ice shelf.

These ice mass changes occurring over the course of glaciation history, especially since the last glacial maximum, cause a **glacial isostatic adjustment (GIA)** of the solid Earth (Whitehouse et al. 2018, Caron et al. 2018). Today, the GIA effect is reflected in a long-term linear trend, with the effective elastic lithosphere thickness and upper mantle viscosity being crucial for the focusing and decay behaviour, respectively. In addition, there is an instantaneous response to changes in ice loading on short time scales which can be in the same order as or even larger than the GIA effect. The combined effect of GIA and present-day deformation can be measured by permanent and/or repeated geodetic GNSS recordings with an accuracy at the level of 1 mm/a (Kappelsberger et al. 2021).

Temporal variations of **supraglacial lakes** are an important indication of the meltwater processes. Knowing the lake volume, it is possible to better quantify the temporal dynamics of meltwater input to the glacier bed and ultimately also to the ocean. While their area can be measured quite well based on time series from optical and radar satellite missions (Hochreuther et al. 2021), the lake depth is still difficult to retrieve. Lake depth measurements are required to integrate this information with the lake area for an estimate of the melt water volume. Together with the drainage geometry and system, this enables to provide information where and approximately how much melt water drains into the glacier.

During the *Polarstern* cruise PS131 we will focus on repeated and permanent GNSS measurements at western Lambert Land (LAMW). Measurements to infer the depth and further parameters of supraglacial lakes will have to be focussed on specific lakes at Nioghalvfjerdsbræ and Zachariae Isstrøm due to the accessibility by the helicopter flights from *Polarstern*.

Work at sea

Our entire programme is related to glaciers and partly ice-free regions in Greenland, see Figure 1.

At the location at western Lambert Land (LAMW, coordinates see Table 11.1) both the GNSS campaign measurements as well as the permanent GNSS installation are planned to be initialised by a preceding land-based field campaign (which is independent from *Polarstern*) in the beginning of July 2022. Hence, the major task will be to check the permanent site and download data as well as to dismantle the campaign equipment, and return the respective equipment to *Polarstern*. A further GNSS equipment has to be recovered from Holm Land (site HOLM) which was set up in September 2017 during the *Polarstern* cruise PS109 but could not be retrieved due to bad weather.

For the measurements of supraglacial lakes, a number of potential candidates (with a depth larger than 4 m) will be identified before the expedition both at Nioghalvfjerdsbræ and Zachariae Isstrøm and in optimum co-location with the GNSS site at western Lambert Land. The exact locations will be decided using topical satellite imagery and, in the end, on site in close coordination with the helicopter crew. We will use a remotely controlled boat to perform measurements of lake depth.

Tab. 11.1: Locactions and coordinates of the geodetic GNSS sites

ID	**Location**	**Latitude (North) [°]**	**Longitude (West) [°]**
LAMW	Lambert Land West	79.22647	22.30611
HOLM	Holm Land	80.27303	16.43153

Preliminary (expected) results

The GNSS observations will be processed at the home institution (so-called post-processing using the Bernese GNSS Software). In the analyses latest standards have to be incorporated used in geodesy (e.g. consistent and precise realization of the reference frame). In the end, we will infer vertical deformation rates.

Measuring supraglacial lake depths with depth larger than 4m will allow establishing empirical functions with multispectral bands and to extend existing algorithms for deeper waters. This will allow to estimate lake depth from Sentinel-2 data as well as to cross-calibrate ICESat-2 data if measurements can be done at respective tracks/lakes.

Data management

The successfully recorded data are raw data and need to be processed at the home institutions. However, the GNSS raw data will be archived at TU Dresden in close coordination with a database which is being maintained in the frame of the SCAR Expert Group on Geodetic Infrastructure in Antarctica (GIANT). Resulting products from the GNSS processing as well as supraglacial lake depth tracks and bathymetry products ascertained from this mission will be published in conjunction with respective scientific papers and archived according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science.

References

Caron L, Ivins ER, Larour E, Adhikari S, Nilsson J, Blewitt G (2018): GIA model statistics for GRACE hydrology, cryosphere, and ocean science. Geophysical Research Letters, 45: 2203– 2212. https://doi.org/10.1002/2017GL076644.

Hochreuther P, Neckel N, Reimann N, Humbert A, Braun M (2021): Fully Automated Detection of Supraglacial Lake Area for Northeast Greenland Using Sentinel-2 Time-Series. Remote Sensing, 13(2), 205.https://doi.org/10.3390/rs13020205.

Pörtner H-O, Roberts DC, Masson-Delmotte V, Zhai P, Tignor M, Poloczanska E, Mintenbeck K, Alegría A, Nicolai M, Okem A, Petzold J, Rama B, Weyer NM (eds.) (2021). IPCC Special Report on the Ocean and Cryosphere in a Changing Climate. Intergovernmental Panel on Climate Change, Geneva, Switzerland. https://www.ipcc.ch/srocc/ (last access: 23 Feb 2021).

Kappelsberger MT, Strößenreuther U, Scheinert M, Horwath M, Groh A, Knöfel C, Lunz S, Khan SA (2021): Validating surface-deformation predictions in north-east Greenland using refined estimates of contemporary ice-mass change and densified GNSS measurements, J. Geophys. Res. Earth Surface, https://doi.org/10.1029/2020JF005860.

Khan SA, Kjær KH, Bevis M, Bamber JL, Wahr J, Kjeldsen KK, Bjørk AA, Korsgaard NJ, Stearns LA, van den Broeke MR, Liu L, Larsen NK, Muresan IS (2014): Sustained mass loss of the northeast Greenland ice sheet triggered by regional warming, Nature Climate Change, https://doi.org/10.1038/nclimate2161.

Mayer C, Schaffer J, Hattermann T, Floricioiu D, Krieger L, Dodd PA, Kanzow T, Licciulli C, Schannwell C (2018): Large ice loss variability at Nioghalvfjerdsfjorden Glacier, Northeast Greenland. Nature Communication, 9 (2768). https://doi.org/10.1038/s41467-018-05180-x.

Mouginot J, Rignot E, Scheuchl B, Fenty I, Khazendar A, Morlighem M, Buzzi A, Paden J (2015): Fast retreat of Zachariae Isstrøm, northeast Greenland. Science, 350(6266), 1357–1361. https://doi.org/10.1126/science.aac7111

Shepherd A, Ivins ER, Rignot E, Smith B, van den Broeke M, Velicogna I, Whitehouse P, Briggs K, Joughin I, Krinner G, Nowicki S, Payne T, Scambos T, Schlegel N, A G, Agosta C, Ahlstrøm A, Babonis G, Barletta VR, Bjørk AA, Blazquez A, Bonin J, Colgan W, Csatho B, Cullather R, Engdahl ME, Felikson D, Fettweis X, Forsberg R, Hogg AE, Gallee H, Gardner A, Gilbert L, Gourmelen N, Groh A, Gunter B, Hanna E, Harig C, Helm V, Horvath A, Horwath M, Khan S, Kjeldsen KK, Konrad H, Langen PL, Lecavalier B, Loomis B, Luthcke S, McMillan M, Melini D, Mernild S, Mohajerani Y, Moore P, Mottram R, Mouginot J, Moyano G, Muir A, Nagler T, Nield G, Nilsson J, Noël B, Otosaka I, Pattle ME, Peltier WR, Pie N, Rietbroek R, Rott H, Sandberg Sørensen L, Sasgen I, Save H, Scheuchl B, Schrama E, Schröder L, Seo K, Simonsen SB, Slater T, Spada G, Sutterley T, Talpe M, Tarasov L, van de Berg WJ, van der Wal W, van Wessem M, Vishwakarma BD, Wiese D, Wilton D, Wagner T, Wouters B, Wuite J (2019): Mass balance of the Greenland Ice Sheet from 1992 to 2018. Nature. https://doi.org/10.1038/s41586-019-1855-2.

Whitehouse PL (2018): Glacial isostatic adjustment modelling: historical perspectives, recent advances, and future directions. Earth System Dynamics, 6(2): 401–429. https://doi.org/10.5194/esurf-6-401-2018.

APPENDIX

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTES

A.2 FAHRTTEILNEHMER:INNEN / CRUISE PARTICIPANTS

A.3 SCHIFFSBESATZUNG / SHIP'S CREW

A.1 TEILNEHMENDE INSTITUTE / PARTICIPATING INSTITUTES

Affiliation	Address
DE.AWI	Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung Postfach 120161 27515 Bremerhaven Germany
DE.CAU	Christian-Albrechts-Universität zu Kiel Christian-Albrechts-Platz 4 24118 Kiel Germany
DE.DRF	DRF Luftrettung gAG Laval Avenue E312 77836 Rheinmünster Germany
DE.DWD	Deutscher Wetterdienst Seewetteramt Bernhard Nocht Str. 76 20359 Hamburg Germany
DE.FAU	Friedrich-Alexander-Universität Erlangen-Nürnberg Institute of Geography Wetterkreuz 15 91058 Erlangen Germany
DE.GEOMAR	GEOMAR Helmholtz-Zentrum für Ozeanforschung Wischhofstraße 1-3 24148 Kiel Germany
DE.HHU	Heinrich-Heine-Universität Düsseldorf Universitätsstraße 1 40225 Düsseldorf Germany
DE.MPIC	Max-Planck-Institut für Chemie (Otto-Hahn-Institut) Hahn-Meitner-Weg 1 55128 Mainz Germany

Affiliation	Address
DE.NHC	Northern HeliCopter GmbH Gorch-Fock-Straße 103 26721 Emden Germany
DE.TROPOS	Leibniz Institut für Troposphärenforschung Permosserstraße 15 4318 Leipzig Germany
DE.TU-Berlin	Technische Universität Berlin Straße des 17. Juni 135 10623 Berlin Germany
DE.TU-Dresden	Technische Universität Dresden Institut für Planetare Geodäsie 01062 Dresden Germany
DE.UNI-Bremen	Universität Bremen Bibliothekstraße 1 28359 Bremen Germany
DE.UNI-Köln	Universität zu Köln Albertus-Magnus-Platz 50923 Köln Germany
DE.UNI-Oldenburg	Carl von Ossietzky Universität Oldenburg Ammerländer Heerstraße 114-118 26129 Oldenburg Germany
DK.KU	Københavns Universitet Nørregade 10 1165 København Denmark
JP.UTOKYO	The University of Tokyo 5-1-5, Kashiwa-no-ha 277-8564 Kashiwa Japan
NO.UIB	Universitetet i Bergen 5007 Bergen Norway

Affiliation	Address
FR.SHOM	Naval Hydrographic and Oceanographic Service 29200 Brest France
NO.METNo	Norwegian Meteorological Institute Henrik Mohns Plass 1 0313 Oslo Norway

A.2 FAHRTTEILNEHMER:INNEN / CRUISE PARTICIPANTS

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
Arevalo Martinez	Damian Leonardo	DE.GEOMAR	Scientist	Chemistry
Babu Suja	Arun	DE.TROPOS	Scientist	Physics
Bartek	Katrina Marie	DE.FAU	PhD candidate	Glaciology
Becker	Hauke	DE.AWI	Engineer	Oceanography
Brauer	Jens	DE.NHC	Pilot	Helicopter Service
Buth	Lena	DE.AWI	PhD candidate	Physics
Colias Blanco	Manuel	DE.NHC	Technician	Helicopter Service
Elliott	Fiona	NO.UIB	Technician	Oceanography
Fer	Ilker	NO.UIB	Scientist	Oceanography
Graupner	Rainer	DE.AWI	Technician	Oceanography
Haas	Christian	DE.AWI	Scientist	Glaciology
Hofmann	Zerlina	DE.AWI	PhD candidate	Oceanography
Hohe	Christian Klaus	DE.AWI	Technician	Biology
Hoppmann	Mario	DE.AWI	Scientist	Oceanography
Jucker	Meret Nia	DE.AWI	Student (Master)	Biology
Kanzow	Torsten	DE.AWI	Scientist	Oceanography
Kirk	Henning	DE.AWI	Technician	Geophysics
Knüppel	Nadine	DE.AWI	Technician	Biology
Koehler	Klara	DE.AWI	Student (Master)	Oceanography
Lion	Victor	DE.CAU	Student (Master)	Other Geosciences
Lochthofen	Normen	DE.AWI	Engineer	Engineering Sciences
Loebel	Erik	DE.TU-Dresden	Scientist	Glaciology
Ludszuweit	Janine	DE.AWI	Technician	Biology
Lüchtrath	Sabine	DE.TU-Berlin	PhD candidate	Other Geosciences
McPherson	Rebecca	DE.AWI	Scientist	Oceanography
Metfies	Katja	DE.AWI	Scientist	Biology
Miehe	Kai	DE.NHC	Technician	Helicopter Service
Monsees	Matthias	DE.AWI	Technician	Oceanography
Morische	Annika	DE.UNI-Oldenburg	Student (Master)	Other Geosciences

Name/ Last name	Vorname/ First name	Institut/ Institute	Beruf/ Profession	Fachrichtung/ Discipline
Murray	Ayla Rosina Cherrington Sealey	DE.AWI	PhD candidate	Biology
Neudert	Mara	DE.AWI	PhD candidate	Physics
Niehaus	Hannah Maria	DE.UNI-Bremen	PhD candidate	Physics
Niehoff	Barbara	DE.AWI	Scientist	Biology
Oehlke	Philipp Wilhelm	DE.TROPOS	Student (Master)	Engineering Sciences
Oldenburg	Ellen	DE.HHU	PhD candidate	Biology
Pinter	Sina Simona	DE.GEOMAR	Student (Master)	Other Geosciences
Rehder	Linda	DE.AWI	PhD candidate	Biology
Reifenberg	Simon Felix	DE.UNI-Bremen	PhD candidate	Oceanography
Rohde	Jan	DE.AWI	Engineer	Engineering Sciences
Rückert	Janna Elisabeth	DE.UNI-Bremen	PhD candidate	Physics
Schlindwein	Vera	DE.AWI	Scientist	Geophysics
Schüttler	Johanna	DE.MPIC	Student (Master)	Chemistry
Spreen	Gunnar	DE.UNI-Bremen	Scientist	Physics
Suter	Patrick	DE.DWD	Scientist	Meteorology
Torres-Valdés	Sinhué	DE.AWI	Scientist	Oceanography
Vaupel	Lars	DE.NHC	Pilot	Helicopter Service
von Appen	Wilken-Jon	DE.AWI	Scientist	Oceanography
Walbröl	Andreas	DE.UNI-Köln	PhD candidate	Meteorology
Winberg von Friesen	Lisa	DK.KU	PhD candidate	Biology
Zeising	Moritz	DE.AWI	PhD candidate	Oceanography

A.3 SCHIFFSBESATZUNG / SHIP‘S CREW

No.	Nachname	Voname	Position
1	Langhinrichs	Moritz	Master
2	Lauber	Felix Thomas	C/Mate
3	Strauss	Erik	C/M Ladung
4	Eckenfels	Hannes	2nd Mate 1
5	TBN		2nd Mate 2
6	Ziemann	Olaf	Chief Eng
7	Rusch	Torben	2nd. Eng
8	Fiedler	Alexander	2nd. Eng 1
9	Ehrke	Tom	2nd. Eng 2
10	Hofmann	Joerg Walter	Elec./Eng Komm.
11	Frank	Gerhard Ansgar Leon	Elec./Eng. Brücke
12	Schwedka	Thorsten	Elec./Eng. Labor
13	Zohrabyan	David Rubeni	Elec./Eng. Labor
14	Pommerencke	Bernd	Elec./Eng. SET
15	Winter	Andreas	Elec./Eng. System
16	Krueger	Lars	Elec./Eng. Winde
17	Brueck	Sebastian	Bosun
18	Weiss	Daniel	MP Rating/D 2
19	Moeller	Falko	MP Rating/D 3
20	Decker	Jens	MP Rating/D 4
21	Buchholz	Joscha	MP Rating/D 5
22	Lutz	Johannes Paul	MP Rating/D 6
23	Lello	Ants	MP Rating/D 7
24	Fink	Anna-Maria	MP Rating/D 8
25	Schade	Tom	MP Rating/D1
26	Waterstradt	Felix	MP Rating/M 1
27	Clasen	Nils	MP Rating/M 2
28	Arnold - Becker	André	MP Rating/M 3
29	Hansen	Jan Nils	MP Rating/M 4
30	TBN		MP Rating/M 5
31	Keller	Jürgen Eugen	Carp. 1
32	Niebuhr	Tim	AB 1
33	Plehn	Marco Markus	Fitter/E 1
34	Schnieder	Sven	Cook 1

No.	Nachname	Voname	Position
35	Martens	Michael	2nd Cook 1
36	Matter	Sebastian Udo	2nd Cook 2
37	Wartenberg	Irina Marion	C/Stwd. 1
38	Ilk	Romy	Stwd./KS
39	Hettwer	Kathrin	2nd Stwd. 1
40	Witusch	Petra	2nd Stwd. 2
41	Golla	Gerald	2nd Stwd. 4
42	Shi	Wubo	2nd Stwd. 4
43	Hu	Guo Yong	2nd Stwd. 5
44	Chen	Quanlun	2nd Stwd. 6
45	Guba	Klaus	Doc. 1